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EFFECTS OF THE SAN JOAQUIN MASTER DRAIN ON WATER QUALITY OF THE SAN FRANCISCO BAY AND DELTA

Federal Water Pollution Control Administration
San Francisco, California

January 1967

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CENTRAL PACIFIC BASINS PROJECT

SAN JOAQUIN MASTER DRAIN

CALIFORNIA

EFFECTS ON WATER QUALITY OF SAN FRANCISCO BAY AND DELTA

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
JANUARY 1967

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EFFECTS OF THE
SAN JOAQUIN MASTER DRAIN
ON WATER QUALITY OF THE
SAN FRANCISCO BAY AND DELTA

by

CENTRAL PACIFIC BASINS
COMPREHENSIVE WATER POLLUTION CONTROL PROJECT

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
SAN FRANCISCO, CALIFORNIA

JANUARY 1967

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I. INTRODUCTION

PURPOSE

The U. S. Bureau of Reclamation and the California Department of Water Resources jointly plan to construct a master drain in the San Joaquin Valley for the purpose of collecting and transporting highly saline agricultural drainage waters to a disposal point in the Sacramento - San Joaquin Delta near the City of Antioch. While there is general agreement that such a drainage project will be required to permit the important agricultural economy of the San Joaquin Valley to continue to prosper, there is less agreement as to the resulting effects on the quality of Delta and San Francisco Bay waters of this plan for disposal. This stems in a large measure from a lack of information on which to base predictions of future water quality in this Bay-Delta tidal system and on how this quality would be affected by the addition of large quantities of agricultural drainage.

From its inception late in 1965 the Central Pacific Basins Comprehensive Water Pollution Control Project of the Federal Water Pollution Control Administration (FWPCA) has devoted its resources to a detailed investigation of this complex problem. Because of the necessity for developing information rapidly so as to avoid unnecessary delay of this important project, the investigation was limited in duration and was completed in December 1966. This report summarizes the findings of that investigation. More detailed descriptions of the investigative methods employed will be published as an appendix to this report.

SCOPE OF THE INVESTIGATION

To predict the effect of the San Joaquin Master Drain on the quality of the Bay and Delta waters, it is necessary to consider it in the context of all other conditions affecting water quality that will exist in the future. This investigation, therefore, has taken into consideration:

1. The future development of the economy of the tributary area,
2. Expected changes in the quantity and quality of all waste water sources,
3. Planned water resource development projects as they will affect the hydrology of the area, and
4. The uses of Bay and Delta waters that will be required in the future for all legitimate purposes.

The future fifty year period, 1970-2020, was examined. All existing information on water requirements, water quality, and pollution problems have been utilized to the maximum possible extent. Laboratory investigations, field studies, and engineering analyses were carried out only to the extent that new information was believed to be necessary for a satisfactory evaluation of present and future conditions. In general, laboratory and field studies were confined to special problems related to evaluation of the effects of nutrients and pesticides and to the study of dispersion characteristics in the receiving waters. The major project effort was devoted to the evaluation and interpretation of available information using, in some cases, special analytical techniques, such as mathematical models, developed for the purpose.

A number of possible plans for the non-pollutional discharge of the San Joaquin Master Drain were considered. The benefits and detriments of each plan were considered and a course of action selected that would adequately protect the quality of the receiving waters.

The efforts of the Central Pacific Basins Project (CPBP) were supplemented to a significant degree by the special studies listed on the following page. These investigations were carried out under contract to the Project, in most cases with the participation and assistance of the Project staff.

AUTHORITY

The Federal Water Pollution Control Administration is the agency of the Federal government having primary responsibility for implementation of a national policy for enhancement of the quality of the nation's water resources through the control of pollution. This policy has been spelled out in a series of legislative acts over the past decade which are described collectively as the Federal Water Pollution Control Act, as amended (33 USC 466a et seq.). Section 3 of this Act calls for the development of comprehensive programs for the control of water pollution in the major interstate river basins of the nation.

The Central Pacific Basins Project was established for this purpose and carried out this investigation as its initial step in meeting the objective of a comprehensive program for pollution control in its area of responsibility.

The FWPCA has, in addition, the responsibility for review and evaluation of all federal water resource development projects for their impact on water quality in accordance with established federal inter-agency procedures. This responsibility was broadened by Executive Order 11288 dated July 7, 1966 which describes procedures for the prevention, control, and abatement of water pollution by Federal activities and installations, such as the proposed San Joaquin Master Drain.

SPECIAL STUDIES PERFORMED FOR FWPCA RELATED TO THE SAN JOAQUIN MASTER DRAIN AND THE SAN FRANCISCO BAY AND DELTA

Investigator	Area of Investigation
U. S. Department of Interior Bureau of Reclamation	Estimation of Future Monthly Inflows, Outflows and Consumptive Use in the Sacramento - San Joaquin Delta
U. S. Army Corps of Engineers	Dye Dispersion Studies in San Francisco Bay Hydraulic Model
Mr. John Skinner, California Department of Fish and Game	Evaluation of Historical, Present and Future Commercial and Sport Fishery and Wildlife Resources of the Bay-Delta System
Prof. David I. Jenkins Univ. of California, Berkeley	A Study of Methods Suitable for the Analysis & Preservation of Nitrogen Forms and Phosphorus Forms in an Estuarine Environment
Prof. Robert Selleck Univ. of California, Berkeley	Laboratory Experiments on Effects of Nutrients on the Primary Productivity of San Francisco Bay
Prof. L. D. Doneen Univ. of California, Davis	Analyses of Drainage Water & Soil Samples and Evaluation of Relationships Between Soil and Water Content of Nitrogen and Total Dissolved Solids
Dr. Gerald Orlob Water Resources Engineers, Inc.	Development and Evaluation of a Mathematical Model of Water Quality in the San Francisco Bay-Delta System
Dr. E. G. Altouney Stanford Research Institute	Recreation and Fishery Values in the San Francisco Bay and Delta
Dr. Ray B. Krone Consultant on Estuarial Sediments	Estimation of Future Amount and Nature of Suspended Sediments in Waters of the San Francisco Bay System
Dr. James B. Lackey Biological Consultant	Assessment of the Effects of Increased Nutrients on the Ecology of San Francisco Bay-Delta System

ACKNOWLEDGMENT

The Federal Water Pollution Control Administration received the assistance and cooperation of many individuals and agencies in the conduct of this investigation. The California Department of Water Resources, in particular, was most helpful by participating jointly with the Central Pacific Basins Project in several important field studies. The many agencies which provided direct assistance are listed below.

U. S. Department of the Interior

- Bureau of Reclamation, Region 2
- Geological Survey
- Bureau of Outdoor Recreation
- Bureau of Sport Fisheries and Wildlife
- Bureau of Commercial Fisheries
- Bureau of Mines

U. S. Department of the Army, Corps of Engineers

- San Francisco District

U. S. Department of Commerce

- Office of Business Economics

State of California

- Department of Water Resources
    - San Joaquin District
    - San Francisco Bay District
    - Sacramento District
- Department of Fish and Game
- State Water Quality Control Board
    - Central Valley Region
    - San Francisco Bay Region

San Francisco Bay Conservation and Development Commission

Contra Costa County Water Agency

II. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The investigations described in this report have led to the following conclusions:

1. The planned discharge of the joint State-Federal San Joaquin Master Drain to the Delta near the City of Antioch would not have significant adverse effects on the quality of waters of the San Francisco Bay-Delta system if adequate pollution control measures are employed. Without such measures, economic losses would become significant by 1980 and possibly as early as 1974 when the Peripheral Canal is scheduled to go into operation.

2. The nitrogen content of the Master Drain waters would, if discharged untreated at Antioch, stimulate the growth of large quantities of planktonic algae and other aquatic plants in the receiving waters. The presence of these plants in great density would have significant adverse effects upon the fishery of the Bay-Delta system. Their presence would also significantly reduce the recreation and aesthetic value of these waters and increase costs associated with their use for boating, navigation, industrial cooling, and other purposes. The monetary value of those detrimental effects for which costs can be estimated is placed at $11 million annually.

3. Augmentation of Delta outflow would be relatively ineffective in reducing losses attributable to the nitrogen content of drain waters.

4. The detrimental effects due to nitrogen in the drain waters could be prevented by treatment which would keep the nitrogen content of the receiving waters from exceeding 2 mg/l. Several effective methods of treatment of drain water to remove nitrate-nitrogen give promise of economic justification. A study has been initiated between the FWPCA, the Office of Saline Water, the Bureau of Reclamation, and the California Department of Water Resources to determine the most feasible method of treatment.

5. The effect of the dissolved mineral salts contained in the drain discharge on the waters of the Delta would be determined by the level at which the minimum outflow from the Delta is controlled in the future. At a minimum Delta outflow of 1500 cfs as proposed by the Bureau of Reclamation, the drain discharge at Antioch would have a beneficial effect by reducing the mean total dissolved solids content of Delta waters used for agriculture, since at that level of sustained outflow the receiving waters would be of a poorer mineral quality than the drain waters.

6. If the minimum Delta outflow were controlled at the level required to meet the "Delta water quality criteria" proposed by the Bureau of Reclamation and the California Department of Water Resources (estimated in this investigation to be approximately 3000 cfs), then the drain discharge at Antioch would increase the mineral concentration of water available to agriculture in the western Delta. The monetary value of this detriment to agricultural water users is estimated to be approximately $1 million annually.

7. The pesticide residues discharged by the Master Drain would not significantly increase the present pesticide concentration of the receiving waters if only sub-surface tile drainage were collected by the Master Drain.

8. Placement of the Master Drain discharge to the west of Antioch at Middle Point in Suisun Bay would cause detrimental effects due to nitrogen enrichment equal in magnitude to those described for the drain discharge at Antioch but would improve the mineral quality of waters in the Delta. Placement of the discharge west of Carquinez Strait would reduce but not eliminate the detrimental effects of nitrogen created by a more easterly discharge and would have no significant effect on the mineral quality of Delta waters.

9. The discharge of the Master Drain to the Pacific Ocean could be accomplished in a manner that would prevent any significant adverse effects on these marine waters.

10. An interim plan for storage of drainage until the studies mentioned above have been completed would eliminate any discharge to the Bay-Delta area and would preclude any water quality problems during the interim period. Such an interim plan would also permit the selection of the final drain terminal point at a later date.

RECOMMENDATIONS

As a result of the above conclusions, it is recommended:

1. that the joint studies mentioned above be vigorously pursued during the next three years with the primary objective of establishing the economic feasibility of treatment of drain waters for the removal of nitrate-nitrogen. At the conclusion of these studies in 1970, a decision should be made by the State and Federal construction agencies between (a) satisfactory treatment of drain waters and discharge of the treated effluent to the Bay-Delta system under conditions that would keep the Delta water nitrogen content below 2 mg/l, and (b) discharge of the drain waters to the ocean. This decision should be reviewed by the Federal Water Pollution Control Administration to insure that the quality of the receiving waters will be protected.

2. that construction of the Master Drain proceed to a northerly point from which the drain waters may be conveyed to either the Delta following treatment or to the ocean; provided that interim storage facilities are also constructed to prevent any discharge from the Master Drain before 1972. Selection of the final terminus of the Master Drain should not be made until completion of the studies mentioned above.

3. that the findings of the California Water Quality Control Board's Bay-Delta Program studies be considered in any decision regarding disposition of Master Drain waters. These findings are scheduled to be available before 1970.

4. that surface drainage (tailwater) from irrigated lands be excluded from the Master Drain because of its relatively high pesticide content. These waters are of acceptable quality for irrigation and should be reused for that purpose without discharge to surface streams. Sub-surface drainage waters should be monitored and those containing excessive quantities of pesticide compounds should receive appropriate treatment prior to entering the Master Drain.

5. that the joint studies mentioned above include further investigations of the characteristics of sub-surface tile drainage, and changes that may occur during transit in the Master Drain. New information developed in these studies would be used to verify the conclusions of this report.

6. that these recommendations be reviewed following the establishment of water quality standards for the San Francisco Bay and Delta as required by the Water Quality Act of 1965 to insure their consistency with those standards.

7. that the State and Federal construction agencies initiate a program of surveillance of water quality conditions at potential receiving water locations. This program should begin without delay and be expanded to include monitoring of drainage water conveyed by the Master Drain to the interim storage facilities. Monitoring of Drain and receiving waters should be continued indefinitely after initiation of the Drain discharge as a routine control procedure.

8. that the relationships between Delta outflow and the quality of water in the Bay-Delta system developed for this report receive continuing study. This work should be carried out by FWPCA in cooperation with water resource development agencies to define the need for storage in future Federal reservoirs for regulation of Delta outflow to control water quality in the San Francisco Bay-Delta system.

III. THE CENTRAL VALLEY DRAINAGE BASIN

PHYSICAL DESCRIPTION

The Central Valley Basin of California is drained by two major river systems, the Sacramento River on the north and the San Joaquin River on the south (see Figure 1). The combined basin extends nearly 500 miles in a northwest-southeast direction and averages 120 miles in width. It includes more than one-third of California and covers some 64,000 square miles. The basin is entirely surrounded by mountains except for a narrow gap in its western edge through which the combined Sacramento - San Joaquin Rivers flow to the Pacific Ocean through the San Francisco Bay. The valley floor is a gently sloping alluvial plain that comprises nearly a third of the total basin area. It is about 400 miles long and averages about 45 miles in width. On the valley floor are 10,300,000 acres of prime agricultural land of which approximately one-half is currently under irrigation.

The climate of the Central Valley varies widely from the warm, two season climate of the valley floor to the colder, four season climate of the Sierra Nevada. On the valley floor, about 90 percent of the rainfall occurs from November to April, while the summers are hot and dry. The San Joaquin River Basin receives considerably less rainfall and has much less surface runoff than the Sacramento River Basin. Since climate and soil conditions are very favorable to irrigated agriculture, ground waters and local surface waters in the San Joaquin Valley have been used to their capacity for this purpose. The southern half of the San Joaquin Valley (Tulare Lake Basin) has no natural drainage outlet. This area contains 4.8 million acres of irrigable land while the remaining portion of the San Joaquin Valley to the north contains 3.2 million acres of irrigable land. Approximately 3.9 million acres in the San Joaquin Valley are presently irrigated of which 2.7 million lie in the Tulare Lake Basin.

The Sacramento - San Joaquin Delta is located at the confluence of the Sacramento and San Joaquin Rivers system. The Delta contains some 738,000 acres, interlaced with 700 miles of meandering waterways covering 50,000 acres. Over 500,000 acres of agricultural lands are irrigated in the Delta and these comprise some of the most productive in California. About 415,000 acres, known as the Delta Lowlands, lie between elevations of 5 feet above and 20 feet below sea level. This area is composed of peat, organic sediments, and alluvium, and is protected from inundation by man-made levees. Waters flowing out of the Delta pass through Suisun Bay, San Pablo Bay, North San Francisco Bay, and finally, through the Golden Gate to the Pacific Ocean. This entire area, including the Delta is subject to tidal action.

The primary study area of this investigation is shown in Figure 2. It includes the Sacramento - San Joaquin Delta, Suisun Bay, San Pablo Bay and San Francisco Bay. Particular emphasis was placed on these waters since they represent the primary area that would be influenced by the proposed discharge of the San Joaquin Master Drain. In addition, attention was directed to the Central Valley to the extent that activities there would influence water quality conditions in the San Francisco Bay and Delta.

MAJOR WATER PROJECTS

Increasing demands for irrigation water beyond that available in the San Joaquin Valley, resulted in the development of the Central Valley Project (CVP) by the Bureau of Reclamation. Existing and authorized units of this project will bring irrigation water to some 3,090,000 acres, over two-thirds of which lie in the San Joaquin Valley. Figure 3 shows the major existing units of this project, as well as additional projects proposed for future construction by State and Federal agencies. The primary objective of the CVP is to store surplus flood waters of the Sacramento River system for use in the San Joaquin Valley. In addition to the yield of Shasta and Folsom reservoirs in the Sacramento basin, water is diverted into this basin from the Trinity River which naturally drains to the Pacific Ocean. These waters are conveyed in the channel of the Sacramento River, drawn across the Sacramento - San Joaquin Delta and pumped into the Delta-Mendota Canal for use in the lower San Joaquin Valley. San Joaquin River water is stored behind Friant Dam and diverted into the Madera and Friant-Kern canals to supply water needs as far south as Bakersfield. Water supplies along the lower San Joaquin River are augmented by releases from the Delta-Mendota Canal. The existing CVP features provide about 1,300,000 acre feet per year of additional water to the San Joaquin Valley primarily for irrigation purposes.

The California Water Plan was developed by the State Department of Water Resources to serve as a master plan to guide the future development of water resources in California. The plan includes local projects to meet local needs throughout the State and also includes the California aqueduct system which will transfer surplus waters from the northern areas of the State to areas of deficiency in the San Joaquin Valley and southern California. The Burns-Porter Act which provided the financial base for construction of the State aqueduct system was approved by the voters in November 1960. The features of this system pertinent to this investigation include:

1. South Bay Aqueduct
2. North Bay Aqueduct
3. Importation of water from the Sacramento River Basin to the San Joaquin Valley via the Delta and the California Aqueduct
4. The San Luis Project
5. The San Joaquin Master Drain

Construction of the South Bay Aqueduct has been completed and water is being delivered from the Delta to the south San Francisco Bay area. The next three projects listed are under construction and nearing completion. The San Joaquin Master Drain is under investigation and nearing the initial construction stage.

The San Luis Project authorized by Congress in 1960 and currently under construction is a joint Federal-State facility designed to provide the San Joaquin Valley with additional irrigation water. The project consists of a 2,100,000 acre foot reservoir in the San Joaquin Valley and appropriate conveyance and pumping facilities to transport surplus waters from the Sacramento River to the reservoir. An enlarged Delta-Mendota Canal and eventually the California Aqueduct will supply water to the reservoir mainly during the off-irrigation season. During the irrigation season, supplemental water will be drawn from the reservoir to supply 1,250,000 acre feet/year to the 600,000 acre Federal San Luis service area and 1,100,000 acre feet/year to State service areas. The San Joaquin Valley service areas are shown in Figure 4. In addition, the Bureau of Reclamation has proposed the San Felipe Unit of the Central Valley Project which would divert water from San Luis Reservoir to coastal areas tributary to Monterey Bay and south San Francisco Bay.

The California Department of Water Resources and the Bureau of Reclamation have recognized that high quality Sacramento River water is degraded as it passes through the channels of the Sacramento - San Joaquin Delta enroute to the export pumps and aqueducts near the City of Tracy. To protect the quality of these export waters, these agencies propose to construct a Peripheral Canal which would isolate and convey waters from the Sacramento River near Hood to the export pumps at Tracy.

The Peripheral Canal would insure the highest quality of export water but as a result a diminution of water quality in the Delta would occur. This drop in quality can be partially controlled by providing flow releases from the Peripheral Canal. These releases would also create a more uniform distribution of flow throughout the Delta.

The Bureau of Reclamation has proposed diversion by pumping from the Sacramento River below the City of Sacramento and by gravity from the American River above that city for the Eastside Division of the Central Valley Project. The waters so diverted would serve to augment supplies in the eastern San Joaquin Valley and in the Tulare Lake Basin. The initial phase of this project would provide approximately 1.5 million acre feet of water to the San Joaquin Valley and the ultimate phase some 3 million acre feet. Eighty percent of this water would be diverted from the lower Sacramento River near the Delta, and the remainder from the American River, a tributary of the Sacramento River.

SAN JOAQUIN MASTER DRAIN PROJECT

The ultimate need for drainage from a large area of agricultural lands in the San Joaquin Valley was recognized late in the last century, but only within the last ten or fifteen years were serious efforts made to accomplish this objective. After hearings in 1956, a State Legislative Committee concluded that agricultural drainage problems existed and were becoming more serious in the Valley. The California Department of Water Resources initiated the San Joaquin Valley Drainage Investigation in 1957 and three years later the Burns-Porter Act authorized San Joaquin Valley drainage facilities as part of the California Water Plan.

Simultaneously, Congressional hearings on the San Luis Unit of the Central Valley Project resulted in the inclusion of drainage provisions in the authorizing legislation, Public Law 86-488, passed in June 1960. This Act required that construction of the San Luis Unit not commence until provision had been made for an interceptor drain to the Delta or until satisfactory assurance had been received that the State of California would provide a master drain for the San Joaquin Valley that would adequately serve the San Luis Unit. The Bureau of Reclamation subsequently developed plans for a San Luis Interceptor Drain.

After first considering separate drains, studies initiated jointly by the Bureau of Reclamation and the California Department of Water Resources in 1963 revealed that significant economies would result from construction of a single Master Drain serving the Federal San Luis service area as well as other areas of the San Joaquin Valley. The joint drain facility, known as the San Joaquin Master Drain, was described in Bulletin No. 127 which was published in January 1965 by the California Department of Water Resources. This report considered the costs of a number of disposal schemes and recommended that the drain be discharged to the San Joaquin River near the City of Antioch. Figure 4 shows the principal routes considered. The recommended discharge point was the least costly of those considered. While considerable data had been gathered on the probable quantity and quality of the drain waters, little information was available concerning the effects of this drainage on receiving water quality.

The San Joaquin Master Drain as presently planned would be about 280 miles in length and would have a capacity at its southern end of 60 cubic feet per second and a terminal capacity at the northern end of 900 cubic feet per second. The annual volume of waste water conveyed would reach approximately 500,000 acre feet by the year 2000. Construction would be accomplished in several stages. The first stage would be constructed from Kettleman City to Antioch and would have a capacity of 120 cubic feet per second at its southern end and 400 cubic feet per second at its terminus. This stage would be in full operation by mid-1970. By 1990 the initial stage would be expanded to a capacity of 270 cubic feet per second at Kettleman City and 900 cubic feet per second at the terminus. A further extension of the drain southward into Kern County would be in operation after 1975.

DELTA WATER BALANCE

As already described, many large inter-basin water transfers, both existing and planned, use the channels of the Delta to effect the transfer of water from the Sacramento basin to the San Joaquin Valley. This cross-Delta flow of water superimposed upon tidal currents, and a net outflow seaward, creates a most complex hydrological situation that significantly affects the quality of water found in the Delta. Since these waters would be most directly affected by the proposed Master Drain discharge, it is important that the present and future hydrology of the Delta be carefully examined. In addition, the quality of San Francisco Bay waters is greatly influenced by the amount of outflow from the Delta. The net Delta outflow for present and expected future conditions is described below.

Inflow to the Delta

The sources of inflow to the Delta and Suisun Bay are the rivers draining the Central Valley - the Sacramento, the San Joaquin and several minor tributaries from the Sierra Nevada referred to jointly as the Eastern Streams. Precipitation within the Delta and storm runoff from local watersheds are minor sources during the winter. The flow of the rivers is typically high during the winter and spring, while flow is at a minimum during late summer. However, development and utilization of the water resources of the Central Valley has altered the natural characteristics of flow to the Delta; more drastic changes are envisioned in the future.

About 70 percent of the flow tributary to the Delta originates in the Sacramento River system with most of the remainder due to the San Joaquin River and its major tributaries.

The flow of major tributaries to the Delta has been, and will continue to be, greatly influenced by the extensive upstream water resource developments previously described. The estimated median annual Delta inflows for various levels of upstream development are presented in Table 1. The Delta inflow of 30,300,000 acre feet per year which is estimated to have existed under natural conditions without man's influence has decreased to 16,800,000 acre feet per year under present upstream development conditions and will decrease still further to 14,200,000 acre feet per year in 2020. Over 95 percent of the decrease in Delta inflow to date is the direct result of consumptive losses from irrigated agriculture in the Central Valley.

It is estimated that the median flow of the Sacramento River at Sacramento during the summer (July) will increase from 674,000 acre feet per month at the present level of development to 958,000 in 1990 and 1,161,000 in 2020.

TABLE 1

ESTIMATED ANNUAL DELTA INFLOW

Source	Median Annual Flow, 1/ 1,000,000 AF/Year				
	Natural	Historical	Present	1990	2020
Sacramento River		15.7	14.0	13.0	12.2
San Joaquin River		3.5	1.8	1.6	1.3
Eastern Streams		1.1	1.0	0.7	0.7
TOTAL	30.3 2/	20.3	16.8	15.3	14.2

1/ Based upon the historical record for the period 1921-22 to 1962-63 [1].

2/ Mean for the period 1907-08 to 1956-57, adjusted for natural conditions. [2].

The combined flow from the San Joaquin River and the Eastern Streams is expected to change from 75,000 to 166,000 acre feet in 1990 and 159,000 acre feet in 2020 for the same monthly period. Possible future project diversions or additional exports to southern California above those presently anticipated in the State Water Plan would result in increased median summer flow in the Sacramento River [1,3].*

Precipitation occurs primarily in the November to March period with essentially no precipitation during the entire summer season. Precipitation which falls directly on the water surface of the Delta channels in a winter month such as January averages 12,780 acre feet.

Local storm runoff was estimated for urban and rural areas within the tributary basin. The estimated January local inflows to the Delta for the present, 1990 and 2020 are 60,700, 78,000, and 102,000 acre feet, respectivel

The California Department of Water Resources has found that there is little if any ground water accretion to the Delta [2]. Ground water was not considered as a source of supply to the Delta in this study.

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*Numbers in brackets refer to corresponding entries in the Bibliography.

The total discharge of municipal wastes and industrial process water in the Delta and Suisun and San Pablo Bays is estimated to total 915 cubic feet per second in 1990 and 1652 cubic feet per second in 2020. These flows and the Drain discharge will constitute a large fraction of the total net outflow from San Pablo Bay in the future.

Export From the Delta

The present and projected exports from the Delta are presented in Figure 5 [1]. Total exports including the Contra Costa Canal and North Bay Aqueduct are expected to increase from slightly under 1,465,000 acre feet per year at the present level of development to 8,388,000 acre feet per year in 1990, nearly a five-fold increase. By 2020, an additional 2,000,000 acre feet per year will be exported.

Losses in the Delta

Consumptive use by agriculture in the Delta totals 1,614,000 acre feet annually [4]. During winter months when consumptive use is limited primarily to evapotranspiration from native vegetation and idle crop land the entire consumptive use is normally satisfied by precipitation. Diversions from the channels during the winter months are usually for the purpose of leaching accumulated salts from the soil. Consumptive use during the growing season is satisfied by precipitation, seepage from the channels, soil moisture, and diversions from the channels. The agricultural consumptive use during the month of July totals 273,000 acre feet and essentially the entire amount must be supplied from the Delta channels since precipitation is normally non-existent. A small fraction of the total (22,600 acre feet in July) is satisfied from soil moisture; i.e. moisture above the water table which was stored during the wet season [California State Department of Water Resources,unpublished information]. The remainder of the consumptive use is supplied from the channels both by controlled diversion and by natural seepage. Normally, the total depletion from the channels greatly exceeds the actual consumptive use by agriculture. During July irrigation waste water returned to the channels totals approximately 90,000 acre feet [5].

Annual evaporation varies from 55 inches at Richmond, California to 105 inches near the City of Tracy [6]. Monthly evaporation from the Delta channels is estimated to be 3,690 acre feet in January and 29,500 acre feet in July.

Municipal water supply for communities surrounding the western Delta and Suisun Bay is derived to some extent from the Delta. The Contra Costa Canal and proposed Kellogg Unit constitute the major supply to Contra Costa County adjacent to Suisun Bay while the proposed North Bay Aqueduct would augment supplies in Solano and Napa Counties. Industrial process water is generally derived from the same sources although direct diversion is practiced in those areas where quality is adequate.

Delta Outflow

The outflow from the Delta has, in the past, been subject to pronounced seasonal variation, the discharge being greatest during the winter and early summer and least during the late summer. The initial development of irrigated agriculture in the Delta and the Central Valley relied upon direct diversion of natural stream flow during the irrigation season, significantly depleting the summer outflow from the Delta. Recent construction of large, multipurpose reservoirs has fostered additional agricultural development while mitigating some of the adverse effects of agriculture upon the summer flow regime. At the present time and in the future the large upstream reservoirs and export pumping plants within the Delta permit essentially complete control of the Delta outflow during the summer. The frequency and occurrence of summer outflow is no longer a natural phenomenon but the result of man's actions upstream.

Maintenance of adequate outflow from the Delta has long been recognized as the key to preventing sea water intrusion into the Delta channels. Early studies by the State of California proposed a chloride limit of 1,000 ppm at Antioch and estimated that a minimum flow of 3,300 cubic feet per second would attain this goal [7]. The Secretary of Interior has expressed the view that "maintenance of a minimum flow of approximately 3,300 cubic feet per second at Antioch... is believed sufficient to prevent salinity incursion in the Sacramento - San Joaquin Delta..." [8]. Relative to its water rights for the Central Valley, the Bureau of Reclamation indicated that up to 6,000 cubic feet per second flow into Suisun Bay may be required to prevent the buildup of salts that would otherwise accumulate in the Delta channels [9]. Criteria have been developed in a proposed contract among the United States of America, the State of California, and a "Delta Water Agency" to protect water quality for agricultural use. These criteria may require a greater minimum outflow than 1500 cubic feet per second which has been considered to be a satisfactory minimum by the Bureau of Reclamation and the California Department of Water Resources.

Hydrologic data prepared by the Bureau of Reclamation for this study provide for the maintenance of a minimum Delta outflow of 1500 cubic feet per second not including the discharge of the San Joaquin Valley Drain [1]. These data formed the general hydrologic basis for this study. However, the effects of increasing the minimum Delta outflow to 3,000 and 6,000 cubic feet per second plus the Drain discharge were also investigated.

The estimated total annual Delta outflow for various levels of development is presented in Table 2. The annual outflow at present is about 53 percent of the natural outflow, but will be only 19 percent in 1990 and 8 percent in 2020.

Median monthly outflow is shown in Figure 6. Summer flow distribution at present is similar to that estimated for natural conditions but there is a marked reduction in spring discharge. The net effect of present upstream development can be characterized as the storage and utilization of surplus runoff without diminution of the low summer flows. The drastic change in flow regime in the future is in sharp contrast. The controlled outflow of 1500 cubic feet per second is significantly lower than natural or present median outflow in the summer months. The controlled outflow will not be restricted to the late summer months but will become the typical flow at all seasons of the year in the future.

TABLE 2

ESTIMATED MEDIAN ANNUAL DELTA OUTFLOW

Level of Development	Median Annual Outflow [1/] Acre Feet Per Year
Natural	29,000,000 [2/]
Historic	18,350,000
Present	15,422,000
1990	5,512,000
2020	2,437,000

[1/] Based upon the historical record for the period 1921-22 to 1962-63.

[2/] Mean for the period 1907-08 to 1956-57, adjusted for natural conditions.

Two aspects of the outflow characteristics are particularly significant in assessing changes in water quality in the study area. The degree of salinity intrusion into the Delta is determined not only by the magnitude of low outflows but by their duration as well. Historically and at the present degree of development, the Delta outflow is estimated to decrease to 100,000 acre feet per month (about 1500 cfs) for one month or less per year, on the average (Figure 7). In the future this low level of outflow is expected to occur more frequently, i.e., seven months during the median year at the 1990 level of development and 9 months in 2020. The concentrations of characteristic waste discharge constituents expected during low flow conditions will be strongly influenced by the degree of flushing of the estuary during the previous winter. Analyses performed for this study indicate that at a flow of 25,000 cubic feet per second a very significant transport through the San Francisco Bay system is accomplished in one month and flushing is essentially complete in two months. Using a criteria for adequate flushing of 2,000,000 acre feet outflow in one month, 3,000,000 in two or 4,000,000 in four, the frequency with which this criteria will be met was calculated and is shown in Figure 8. Historically and at the present, adequate flushing and removal of accumulated pollutants has occurred essentially every winter. In 2020 adequate flushing will be obtained only one year in three. It appears that at present the annual occurrence of flushing flows prevents the build-up of pollutants to maximum or steady-state concentrations in the receiving water. In the future, however, low outflows from the Delta will be sustained over longer periods of time and will allow these higher steady-state concentrations to be approached much more frequently.

IV. ECONOMY OF THE STUDY AREA

Estimates of probable location and magnitude of future population growth and industrial development are necessary in an evaluation of future water pollution problems in the Bay-Delta system.

BAY-DELTA AREA

To provide a basis for estimating the future use of water and the amount of wastes generated in the San Francisco Bay and Delta area, a detailed analysis was made of population and economic activity. The primary study area selected for this analysis includes the counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, Sonoma, Sacramento, and San Joaquin. An analysis of the entire Central Valley Basin was also made, but not in as great detail.

Recent Growth

Population. From April 1950 to July 1965, the total population of the study area increased by 2,050,700 - from 3,159,200 to 5,209,900. As shown in Table 3, growth of population by county during the 1950-60 period varied widely. San Francisco County, for example, lost population while Santa Clara County increased its population 121 percent. The overall population increase was 65 percent from 1950 to 1965.

Employment. Employment in the study area increased from 1,265,890 in 1950 to 1,718,213 in 1960, an increase of 35.7 percent. Since employment statistics are reported by place of residence rather than place of employment, percentage increases in employment by county as presented in Table 4, correspond very closely with percentage increases of population, Table 3. Employment in agriculture, forestry and fisheries, manufacturing of textile mill products, and railroads and railway express declined during the 1950-60 period. Employment in all other industrial categories increased, with dominant increases occurring in professional services and manufacture of electrical and other machinery. A listing of the 32 industrial categories included in this analysis is presented on the following page.

Future Growth

Population. Population projections were developed in several steps. First, a review and evaluation of previous population projections was made for the Bay area counties [10-14], California and the Nation. Next, current available information on population, birth, and death rates, migration, and age distribution of the population was analyzed individually and collectively to provide a basis for judging and adjusting available population projections for the San Francisco Bay-Delta area. From this

COMPONENTS OF ECONOMIC ACTIVITY FOR WHICH EMPLOYMENT TRENDS WERE DETERMINED

Commodity Producing

- Agriculture
- Forestry and Fisheries
- Mining
- Manufacturing:
  - Food and Kindred Products
  - Textile Mill Products
  - Apparel
  - Lumber Wood Furniture
  - Printing and Publishing
  - Chemicals and Allied Products
  - Electrical and Other Machinery
  - Motor Vehicles and Equipment
  - Other Transportation Equipment
  - Other and Miscellaneous

Facilities, Distribution and Utilities

- Contract Construction
- Railroads and Railway Express
- Trucking and Warehousing
- Other Transportation
- Communications
- Utilities and Sanitary Services

Trade

- Wholesale Trade
- Food and Dairy Product Stores
- Eating and Drinking Places
- Other Retail Trade

Finance

- Finance
- Insurance
- Real Estate

Services

- Hotels and Other Personal Services
- Private Households
- Business and Repair Services
- Entertainment, Recreation Services
- Medical, Other Professional Services

Public Administration, Armed Forces, and Other

TABLE 3

POPULATION

SAN FRANCISCO BAY - DELTA AREA
(In Thousands)

County	April 1950	April 1960	Est. July 1965	Percentage Change 1950-60	Percentage Change 1960-65
Alameda	740.3	908.2	1,003.1	22.68	13.75
Contra Costa	299.0	409.0	509.9	36.79	24.67
Marin	85.6	146.8	188.7	71.15	28.54
Napa	46.6	65.9	75.7	41.42	14.87
San Francisco	775.4	740.3	750.5	- 4.53	1.38
San Mateo	235.7	444.4	532.2	88.54	19.76
Santa Clara	290.5	642.3	891.2	121.10	38.75
Solano	104.8	134.6	159.9	28.44	18.80
Sonoma	103.4	147.4	178.4	42.55	21.10
Subtotal	2,681.3	3,638.9	4,318.9	35.71	18.69
Sacramento	277.1	502.8	617.2	81.45	22.75
San Joaquin	200.8	250.0	273.8	24.50	9.52
TOTAL	3,159.2	4,391.7	5,209.9	39.01	18.63

TABLE 4

EMPLOYMENT

SAN FRANCISCO BAY - DELTA AREA

County	1950	1960	Percentage Change
Alameda	293,964	355,376	20.89
Contra Costa	114,801	144,229	25.63
Marin	32,798	56,807	73.20
Napa	14,893	21,861	46.79
San Francisco	351,453	364,300	- 1.47
San Mateo	91,471	176,745	93.22
Santa Clara	103,077	233,560	126.59
Solano	42,552	50,341	18.30
Sonoma	36,701	49,696	35.41
Subtotal	1,081,710	1,434,915	32.65
Sacramento	110,395	194,272	75.98
San Joaquin	73,785	89,026	20.66
TOTAL	1,265,890	1,718,213	35.73

analysis, the population of the primary study area is projected to increase to 16,118,000 by the year 2020, a 3.7 fold increase over 1960. A summary of population by County is shown in Table 5.

Employment. Projections of economic growth for the San Francisco Bay-Delta area from 1960 to 2020 are based upon analysis of trends in employment for the 32 components of economic activity as presented above using the 20-year span 1940-60 as the base period.

The procedure used in developing employment projections involved the use of projected population, application of appropriate percentages of total population employed, and distribution of the total employed among the industrial categories. The procedure used follows the well-known and generally accepted principle that the projections for large geographical areas and for aggregate measures of an economy are more reliable than those for small areas or individual segments of an economy. Thus, the procedure uses projected populations as the most reliable indicator of future growth. Population is then used as the basis for estimating the number of jobs needed to support the population. Projected total employment is first disaggregated into six major groups of economic activity and then into sub-activities within each major group. The disaggregation is controlled by projecting the historical trends by individual major group and sub-activity. Consistency and balance within the economy is maintained throughout the process.

The results of this analysis are summarized in Table 6 for the eleven counties of the Bay-Delta study area for six major economic groups which comprise the 32 industrial categories. Figure 9 presents a comparison of population and employment for the eleven Bay-Delta counties.

Detailed breakdowns of the population and employment projections developed above provided the basic information for estimating future municipal and industrial water requirements and future waste loads generated by population and economic activity in the San Francisco Bay-Delta area.

CENTRAL VALLEY BASIN

The combined population of the San Francisco Bay and Central Valley areas in 1960 totaled slightly over 6 million. The area contains 6,141,000 acres of irrigated land, 881,000 acres of urban land and the applied fresh water requirement exceeded 22.7 million acre feet. Population of the total study area is projected to increase to 23.1 million by 2020 while the applied water requirement is projected to increase to 34.8 million acre feet [3]. Current and future population, irrigated and urban land use, and water requirements of the total study area are graphically illustrated in Figures 10, 11, and 12.

TABLE 5

POPULATION
SAN FRANCISCO BAY - DELTA AREA
MEDIAN LEVEL PROJECTIONS, 1960-2020
(In Thousands)

County	1960	1970	1980	1990	2000	2010	2020
Alameda	908.2	1,107	1,279	1,700	2,046	2,375	2,451
Contra Costa	409.0	623	758	1,060	1,339	1,632	1,768
Marin	146.8	237	288	403	508	620	669
Napa	65.9	85	114	172	233	302	346
San Francisco	740.3	770	812	862	888	910	920
San Mateo	444.4	645	733	960	1,135	1,294	1,310
Santa Clara	642.3	1,127	1,321	1,783	2,177	2,568	2,692
Solano	134.6	186	259	407	565	749	870
Sonoma	147.4	206	280	430	589	771	886
Sacramento	502.8	716	962	1,452	1,969	2,532	3,150
San Joaquin	250.0	296	361	529	677	850	1,056
TOTAL	4,391.7	5,998	7,167	9,758	12,126	14,603	16,118

TABLE 6

EMPLOYMENT
ELEVEN BAY-DELTA COUNTIES
(Thousands of Employees)

Major Economic Activity	1940	1950	1960	1970	1980	1990	2000	2010	2020
Commodity Producing	212	283	400	553	668	919	1,155	1,407	1,566
Facilities, Distribution & Utilities	125	211	239	327	390	529	654	785	860
Trade	171	268	305	417	499	680	845	1,020	1,128
Finance	44	65	96	132	158	216	269	325	360
Services	173	252	392	535	639	868	1,080	1,303	1,441
Public Administration, Armed Forces and other	66	187	286	381	445	593	720	843	910
Total	791	1,266	1,718	2,345	2,799	3,805	4,723	5,683	6,265
Percentage of Total Population	38.8	40.1	39.1	39.1	38.8	39.0	38.9	38.9	38.9

V. WATER USES

The waters of the San Francisco Bay-Delta system are extensively used for a wide range of beneficial purposes. In December 1966, the San Francisco Bay Regional Water Quality Control Board adopted a resolution protecting the following beneficial uses of tidal waters inland from the Golden Gate and within the San Francisco Bay Region which excludes the Delta [15].

- Domestic water supply, seasonally
- Industrial water supply year around and/or seasonally
  - Boiler
  - Cooling
  - Rinsing
  - Processing
- Agriculture
  - Irrigation
  - Livestock watering
- Recreation
  - Whole body water contact
    - Swimming
    - Water skiing
    - Skindiving
  - Limited body water contact
    - Pleasure boating
    - Fishing and hunting
    - Marinas
  - Shell fishing
- Fish and wildlife propagation and sustenance
  - Fish habitat, migration and spawning
  - Shrimp and crab habitat
  - Shellfish habitat
  - Waterfowl and other water-associated birds' habitat, resting and reproduction or nesting
  - Mammal rookery and hauling grounds (for harbor seals)
- Navigation
  - Port facilities
  - Shipping facilities
- Aesthetic appeal

With the exception of beneficial uses related to strictly marine water such as crab habitat and mammal rookery and hauling grounds, all of the above uses are recognized in the Sacramento - San Joaquin Delta. In addition to these beneficial uses which generally involve the direct use of the water in some manner, there are indirect uses of the waters as well. These include beach sunbathing, nature walking, sightseeing, photography, bird watching, scenic residential, commercial, and industrial shoreline site location. Beneficial water uses of the Bay-Delta system can be broadly classified into two categories: 1) withdrawal uses, which refers to the direct removal of water for municipal, industrial or agricultural purposes, and 2) instream uses, which include all other uses that take place in, on, or around a public body of water such as recreation, fish and wildlife propagation, navigation and aesthetic enjoyment.

WITHDRAWAL USES

Agricultural, municipal, and industrial users currently divert approximately six million acre feet annually from the San Francisco Bay-Delta system. Of this amount, about two million acre feet/year are diverted from the San Francisco Bay system west of the Sacramento - San Joaquin Delta and the remainder from the Delta. Table 7 summarizes present water diversions from the Bay-Delta system.

San Francisco, San Pablo and Suisun Bays [16]

The agricultural, municipal, and a small fraction of the industrial diversions from these Bays are seasonal because of variations in salinity. These seasonal uses amount to less than one percent of the total diversions.

Agricultural diversions average 4900 acre feet annually, all of which is diverted from the eastern Suisun Bay area. Future demand for agricultural water is estimated by current users at 8,000 acre feet/year.

The only existing municipal use is from Mallard Slough opposite Chipps Island where approximately 6100 acre feet per year is diverted by the Contra Costa Water District during those months when salinity incursion is at a minimum.

Thirty industrial plants are reported to divert waters from these Bays. Water use data are available for 27 of these. Their combined use during the period 1960-1963, was about two million acre feet annually, of which over 97 percent was used for cooling, and the remainder for plant processes, treating and/or diluting wastes in controlled ponds, and for boiler feed. These 27 industries estimate their ultimate need for water at 2,381,000 acre feet annually.

Sacramento - San Joaquin Delta [17-19]

Existing. Existing agricultural diversions from Delta channels are estimated to average about 3.6 million acre feet annually. About 38

TABLE 7

PRESENT WATER DIVERSIONS SAN FRANCISCO BAY AND SACRAMENTO-SAN JOAQUIN DELTA

(Acre-Feet/Year)

	Fresh	Brackish [2/]	Total
San Francisco Bay [1/]			
Municipal	6,100	-	6,100
Industrial	3,100	2,007,000	2,010,100
Agricultural	4,900	-	4,900
Subtotal	14,100	2,007,000	2,021,100
Delta			
Municipal	26,900 [3/]	-	26,900
Industrial	87,700 [3/]	200,000	287,700
Agricultural			
Local	2,234,100	-	2,234,100
Export	1,389,000	-	1,389,000
Subtotal	3,737,700	200,000	3,937,700
Total			
Municipal	33,000	-	33,000
Industrial	90,800	2,207,000	2,297,800
Agricultural			
Local	2,239,000	-	2,239,000
Export	1,389,000	-	1,389,000
TOTAL	3,751,800	2,207,000	5,958,800

[1/] Includes San Pablo and Suisun Bays.

[2/] Primarily cooling water and includes that diverted by steam-electric plants.

[3/] Includes diversions into the Contra Costa Canal.

percent or 1.4 million acre feet, is diverted to the Bureau of Reclamation's Delta-Mendota Canal for export to agricultural lands lying along the western slope of the San Joaquin Valley. The balance is diverted for the irrigation and leaching of over 500,000 acres of Delta agricultural lands which are some of the most productive in California.

Existing diversion of fresh water from the Delta for municipal use totals 26,900 acre feet annually. Most of this water is diverted from Rock Slough to the Bureau of Reclamation's Contra Costa Canal for subsequent distribution by the Contra Costa County Water District. The City of Antioch has, since the early 1900's, diverted their municipal supply from the San Joaquin River for an average of 9 months each year. During periods of poor quality due to salinity incursion, the City diverts water from the Contra Costa Canal. The greater Vallejo area diverts municipal water from an arm of Cache Slough, located in the northern Delta.

Industrial diversions from Delta channels total about 287,700 acre feet annually of which about 70 percent is used for cooling purposes. Industrial fresh water supplies are obtained primarily from the Contra Costa Canal and by direct diversion from Delta channels.

Future. Future fresh water diversion from the Delta can be divided into two categories - 1) local diversions and 2) export diversions. The first category consists of diversions from Delta channels to satisfy municipal, industrial and agricultural water uses in, and immediately adjacent to, the Delta. The second category consists of all water that will be exported from the Delta in the future by both the Bureau of Reclamation and the State of California. Total Delta fresh water diversions for both categories are projected to increase from the present 3.7 million to 12.5 million acre feet annually by the year 2020, as shown in Table 8.

Local Delta fresh water diversions, presently about 2.3 million acre feet per year, are projected to increase about 15 percent by 2020. This is due primarily to municipal and industrial requirements which will increase by 260 percent while local agricultural diversions will increase by about 5 percent.

Fresh water exported from the Delta is projected to increase by almost 600 percent by the year 2020. Of the total water to be exported in 2020, Bureau of Reclamation projects will require 5.8 million acre feet and those of the State of California about 4.1 million acre feet annually.

Approximately 60 percent of the total export water will be used for agricultural purposes, primarily in the San Joaquin Valley, and the balance will be used for municipal and industrial purposes, primarily in southern California. It is probable in the future that all water

TABLE 8

FUTURE FRESH WATER DIVERSIONS
SACRAMENTO - SAN JOAQUIN DELTA
(Acre Feet/Year)

Withdrawal Use	1990	2020
Local[1/]		
Agriculture	2,400,000	2,400,000
Municipal	79,000	130,000
Industrial	160,000	280,000
Sub-Total	2,600,000	2,800,000
Export		
Agriculture	5,200,000	6,400,000
Municipal	2,100,000	2,500,000
Industrial	690,000	830,000
Sub-Total	8,000,000	9,700,000
TOTAL	10,600,000	12,500,000

1/ Local uses include diversions to Contra Costa Canal and Kellogg Projects.

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exported from the Delta region (with possible exception of the North Bay Aqueduct) will be diverted directly from the Sacramento River near Hood by the proposed Peripheral Canal and conveyed to appropriate service areas. This will be done to prevent commingling with poorer quality Delta waters. Municipal and industrial water requirements in northeastern Contra Costa County would then be supplied from the Peripheral Canal facilities in lieu of the existing practice of diverting from western Delta channels because of expected deterioration of these waters by salinity incursion.

INSTREAM WATER USES

San Francisco Bay and Delta waters provide a unique natural environment for extensive instream water uses [20, 21]. The Bays provide some 500 square miles (320,000 acres) of water surface and the Delta, 700 miles of interconnecting waterways covering 50,000 acres. With a mild, even climate and strategic location, this body of water provides a matchless natural harbor and habitat for probably the greatest variety of fish and wildlife species of any comparable body of water in California. The cosmopolitan area surrounding the Bay is often described as one of the most beautiful in the world. It is also a great commercial and industrial center, the western terminal of transcontinental railroads, highways and airlines. The vast network of metropolitan areas, satellite cities and residential areas surrounding the Bay and Delta had a combined population in 1966 of over 5 million. The Bay-Delta waters provide nearby recreation opportunities for this multitude. It is estimated that the total recreational use of these waters in 1965 of 17.9 million participation days will increase to about 75.7 million days in 2020. Principal instream uses of this unique body of water include pleasure boating, water-contact sports, fishing, fish and wildlife propagation, hunting, navigation, and waste water effluent dispersion. Table 9 summarizes the recreational uses of the Bay-Delta system and the estimated value of each use.

Virtually all of the Bay-Delta waters having sufficient depth are used for pleasure boating. Sailing is very popular on the Bays, while motor boating predominates in the Delta. Recreational boating, exclusive of boat fishing, was enjoyed by an estimated 1.9 million days of participation during 1960. Pleasure boating use of Bay-Delta waters is projected to increase to 15.6 million participation days by the year 2020.

Water contact sports are also popular. This use in 1965 was estimated to total 6.6 million participation days and is projected to increase to 31.1 million days annually by the year 2020.

The Bay and Delta comprise a unique and varied water environment for a great variety of fish and wildlife species. At least six species of anadromous fish run into or through the Bay-Delta system going to or from spawning grounds. The king and silver salmon and steelhead pass through the Bay and Delta on their upstream spawning migrations and the young later move seaward through the same waters. Millions of shad and Sacramento smelt migrate through the area. Striped bass, the most popular Delta sport fish, also migrate from the ocean and Bays to the Delta and upstream. Most of the striped bass spawn in fresh water areas of Delta channels. The young use Delta waterways and the Bays as nursery areas. The striped bass fry population in Suisun Bay alone has been estimated to total 35 million.

More than 150 other species of fish inhabit Bay and Delta waters. The most important of these are sturgeon, jacksmelt, perch, herring, anchovies, sole, tom cod, flounder, channel and white catfish, black bass, crappie, and sunfish. Bait fisheries for anchovy, herring, shrimp, and clams are now developing in the Bay. The California Department of Fish and Game believes that the Bay has immense potential for the restoration

TABLE 9

ANNUAL RECREATION USE AND VALUE
SAN FRANCISCO BAY - SACRAMENTO-SAN JOAQUIN DELTA

Activity	1965		1990		2020	
	Participation days (Millions)	Dollars (Millions)	Participation days (Millions)	Dollars (Millions)	Participation days (Millions)	Dollars (Millions)
Sunbathing and Swimming	5.01	5.01	12.3	12.34	21.1	21.08
Sightseeing	4.38	4.38	11.0	11.00	20.8	20.77
Fishing	3.40	8.68	5.8	18.04	9.2	32.81
Boating 1/	2.41	3.62	5.6	8.31	10.4	15.55
Water Skiing	1.61	2.42	5.7	8.51	10.0	14.93
Picnicking	0.60	.75	1.13	1.77	2.1	3.26
Nature Walking	0.30	.30	0.7	0.68	1.4	1.37
Hunting 2/	0.12	.54	0.3	0.42	0.5	0.69
Camping	0.10	.15	0.3	0.42	0.5	0.69
Hiking	0.02	.02	0.1	0.06	0.1	0.10
TOTAL	17.95	25.87	42.5	61.76	75.7	111.19

1/ Excludes boat fishing.

2/ Water fowl only.

of the culture and harvest of oysters and clams [21]. Water quality and public health restrictions preclude shellfish harvesting at the present time.

Sport fishing is a major beneficial use of the Bay-Delta waters. Sport fishing, including offshore ocean salmon fishing, totaled about 3.4 million participation days in 1965. Striped bass fishing was by far the most popular, accounting for approximately 58 percent of the total effort. Most of the salmon caught by Bay area fishermen are caught in the ocean. Sport fishing use of the Bay-Delta fisheries is projected to increase to 9.2 million participation days by 2020.

Commercial fishing for other than bait-fish is prohibited in Bay-Delta waters. However, it has been estimated that about 80 percent of the statewide commercial king salmon ocean landings are attributable to salmon originating in Bay-Delta tributary streams. These were estimated to average 5.8 million pounds annually during the 1955-1964 period.

The marshlands, mudflats, and permanent water areas in the Bay-Delta system support large populations of waterfowl. It is estimated that about 200,000 waterfowl spend the summer here. The Bay-Delta system is of prime importance to the Pacific flyway. About 900,000 waterfowl winter here and an unknown number pause to rest and feed during their migrations between their nesting and wintering areas. The Suisun Bay marshes are the principal remaining waterfowl habitat in the Bay-Delta area. Loss of this area would be a severe blow to the Pacific flyway.

Waterfowl hunting is a major sport. Much of the hunting is done on lands controlled by over 240 duck clubs. From 1955 to 1964, the average number of hunter days was about 140,000 with a success rate of 2.12 birds per hunter day. Because more than half the tidelands can be developed, and because further industrial and commerce-associated navigational development is expected, it is estimated that at least 25 percent of the present waterfowl resource area will not be available to hunters by 2020. The success rate, due to the decrease in the resource, is expected to decline to one bird per hunter day by 2020. Furbearers include muskrat, beaver, river otter, and harbor seal. Muskrat is the principal furbearer trapped.

San Francisco Bay and Delta channels are extensively utilized by vessels ranging from small boats to deep-draft commercial freighters, super tankers, and warships. In 1965, waterborne commerce exceeded 40 million short tons. By 2020, waterborne commerce is projected to increase to about 125 million short tons. Petroleum products currently account for about 70 percent of the waterborne commerce. Vegetable food products and beverages, non-metallic minerals, metals and manufacturers, chemicals, wood and paper account for about 86 percent of the ocean-bound general cargo.

VI. WASTE WATER INPUTS

A realistic analysis of the effects of the San Joaquin Master Drain discharge upon the Bay and Delta waters requires that other significant waste sources be considered as well. For this reason, constituents which are common to both the Drain waste waters and all other waste sources were estimated for present and future conditions and are included in the analysis. The constituents considered in this study were BOD (ultimate carbonaceous biochemical oxygen demand), nitrogen, phosphorus, pesticides, chlorides, boron, and total dissolved solids. Waste sources considered were municipal and industrial waste discharges, waste water from irrigated agriculture, and storm water runoff.

MUNICIPAL AND INDUSTRIAL WASTES

Estimates of future waste loads for the San Francisco Bay and Delta were based on future population and employment projections and waste loading coefficients which were developed from available information on existing waste discharges [22-25]. Municipal waste discharges containing industrial contributions account for more than 93 percent of the total waste discharged in the area excluding Contra Costa County where large industrial water users discharge their wastes separately. Waste load coefficients were developed for each municipal discharge and for each major industrial category in Contra Costa County.

An example of the relationship existing between tributary population and nitrogen content of untreated municipal wastes in the study area is presented in Figure 13. A similar relationship was obtained for BOD, phosphorus and waste flow. These relationships were employed to derive the waste load coefficients which were then used for making projections of future conditions.

It has been assumed that primary and secondary waste treatment processes for municipal wastes will provide the removal efficiencies summarized in Table 10 [26-29]. Present waste treatment methods do not provide consistently effective removal of phosphorus, although some improvement may occur in the future [30, 31].

Raw and treated BOD and nitrogen waste loads from tributary areas of eleven San Francisco Bay and Delta counties are presented in Figures 14 and 15. The treated waste loads are for treatment levels existing in 1960. Secondary treatment of all wastes was assumed for 1990 and 2020.

At present, waste loading is heaviest from Alameda and Contra Costa Counties. Future waste loads will be heaviest from Contra Costa County if projected industrial and employment growth is realized.

TABLE 10

BOD AND NITROGEN REMOVAL EFFICIENCIES

	Removal - Percent	
	Primary Treatment	Secondary Treatment
BOD	30	85
Nitrogen	15	40

A summary of the treated municipal and industrial waste loads contributed by the Bay-Delta area, including total dissolved solids, chlorides, nitrogen, phosphorus and BOD, is presented in Table 18.

The untreated nitrogen and BOD components generated in the San Francisco Bay area have been compared with those generated from municipal and industrial sources in the Central Valley and are presented in Figures 16 and 17. The very large contribution resulting from the concentration of population and industrial activity in the Bay area is evident from this comparison.

AGRICULTURAL WASTES

The growth of plants results in a consumptive loss of water to the atmosphere through the process of evapotranspiration. Though the applied water contains dissolved salts, only negligible amounts of these materials are retained by the plant and, as a result, they remain in the soil. If this buildup of salts is allowed to continue, the soil will eventually become unsuitable for the raising of crops.

In irrigated agriculture, the soil salt buildup process may be controlled through the application of water in excess of plant needs and by percolation of this excess water through the root zone of the plant. The resulting leachate will contain, in addition to its original salt content, those salts formerly present in the water lost through evapotranspiration and any salts dissolved from the soil. The composition of salts in the leachate may be considerably different from that of the applied water depending upon the ion exchange capacity of the soil. It will also contain some fraction of pesticides, fertilizers and soil amendments applied to enhance agricultural production. The soil solution (water retained in the soil) will usually have a salt concentration from three to ten times greater than that of the applied water.

"Irrigation efficiency" is frequently used to express the relationship between water applied and water used by crops. An irrigation efficiency of 80 percent, for example, refers to the consumption by crops of four-fifths of the applied water. The remaining one-fifth of the water may drain naturally in a vertical direction toward a deeper ground water stratum or laterally along the surface or through the soil to be intercepted by surface watercourses. While this process permits further agricultural production, it can lead to serious degradation of ground and surface water quality.

Adequate drainage is essential in order to provide for the removal of excess salts from the root zone and to provide a well aerated condition in the soil which will assure continued agricultural production. When natural drainage is inadequate or where it is desired to reduce deterioration of ground water quality, artificial drains may be installed to collect and dispose of sub-surface saline waters. Collection of this type of drainage water is the function of the San Joaquin Master Drain.

San Joaquin Master Drain

Problems of high ground water and soil salinity existing in the areas of the San Joaquin Valley shown in Figure 4 are expected to increase significantly in the future. The installation of sub-surface tile drains in the affected areas will effectively control the ground water level and eventually lead to the establishment of a satisfactory salt balance in the soil. Sub-surface drains have proven effective in the Imperial Valley of California where almost 300,000 acres are affected. Approximately ten thousand acres are tile drained in the San Joaquin Valley today. Sub-surface drains are expected to serve close to one million acres when the San Joaquin Drain becomes fully operational [33].

Major crops in the areas to be served by drains are cotton, alfalfa, grain and field crops. No significant change in crop patterns is expected in the future, as indicated in Table 11.

Quantity of Flows. Tile drainage is expected to total 53,500 acre feet in 1969 and to increase steadily to 498,000 acre feet annually by the year 2000. A maximum annual flow of 595,000 acre feet is estimated for the year 2050. Peak tile drain flows will occur during May through August, but reservoirs will be employed to regulate these flows. The expected distribution of regulated Master Drain effluent for the year 2000 is presented in Table 12 [34].

Mineral Content. A study of existing tile drains and soil cores collected from the drainage problem areas in the San Joaquin Valley indicates that the soils contain substantial quantities of unleached salts. Studies of leaching efficiencies and expected agricultural practices have led to the estimated concentrations of total dissolved solids and chlorides summarized in Table 13. Also presented are the estimated annual quantities of drainage at ten year intervals.

TABLE 11

CROP PATTERNS IN DRAINAGE PROBLEM AREAS

Crop	Crop Acreage 1960	Crop Acreage 1990
Alfalfa	116,000	115,000
Alfalfa Seed	29,000	32,000
Pasture	81,000	81,000
Cotton	201,000	216,000
Sugar Beets	7,000	7,000
Miscellaneous Field	138,000	146,000
Potatoes	3,000	3,000
Miscellaneous Truck	47,000	48,000
Rice	24,000	24,000
Grain	299,000	299,000
Deciduous	13,000	13,000

Source of data: California Department of Water Resources

TABLE 12

MONTHLY DISTRIBUTION OF REGULATED DRAIN FLOWS IN 2000

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
% Ann. Flow	4.58	4.29	9.47	11.37	11.64	11.37	11.64	11.64	9.95	6.54	4.48	3.03

Source of data: California Department of Water Resources

TABLE 13

QUANTITY AND SALINITY OF SUB-SURFACE DRAINAGE
SAN JOAQUIN AND TULARE BASINS

Year	Drainage Acre Feet/Year	Chlorides mg/l	Total Dissolved Solids mg/l
1970	63,000	1,000	6,820
1980	215,500	830	4,650
1990	391,500	750	3,470
2000	497,500	720	3,080
2010	517,000	690	2,700
2020	536,500	670	2,500

Source of data: California Department of Water Resources

Nutrient and Organic Content. Nitrogen concentrations in tile drainage are dependent on fertilizer application, soil permeability, the amount of water applied, type of crops raised, denitrification, and organic and nitrate-nitrogen in the native soil. The most significant source of nitrogen will probably be fertilizers. Estimated present and future fertilizer use by tributary basin is presented in Figure 18. Heaviest fertilizer use occurs in the Tulare Basin, a condition that is expected to continue.

After nitrification of the fertilizer, the nitrate ion moves relatively easily through the soil column. Cotton is one of the primary crops in the drainage problem areas and nitrogen fertilizer application for this crop ranges from 100 to 150 lbs. of nitrogen per acre annually. Vegetable crops are also heavily fertilized. The observed concentrations of total nitrogen for 30 tile systems in the San Joaquin Valley have ranged from 0.4 to 103.4 mg/l. The California Department of Water Resources estimates the average nitrogen concentration in drainage from the problem area will be 21 mg/l, of which over 95 percent will be as nitrate-nitrogen. Based on a review of available data on existing tile systems in the San Joaquin Valley and considering the cropping patterns, this value appears realistic and has been adopted as representative of probable future levels of nitrogen in Drain waters. However, because of the capability of this and other constituents in the Master Drain effluent to cause pollution problems in receiving waters, further detailed study of tile drain characteristics would be most desirable.

Phosphorus concentrations from 0.06 to 0.39 mg/l have been observed in existing San Joaquin tile drain waters. Because of the low solubilities of phosphate salts and their affinity for soils, the concentrations of phosphorus in tile drainage are not expected to be directly related to phosphate fertilizer application. The estimate of average phosphorus concentration (0.11 mg/l as phosphorus) developed by the California Department of Water Resources for the Master Drain waters is considered to be a reasonable one based on available information.

The BOD of tile drainage from the San Joaquin and Tulare Basins will be very low due to the filtering effect of the soil column and the low organic content of the soils. The carbonaceous BOD is estimated to be 2.0 mg/l.

Pesticide Content. The pesticide content of tile drainage is dependent upon 1) the type of crops grown, 2) the compounds selected for pest control, 3) pesticide application practices, and 4) the properties of the soil through which the compound must move.

Of the crops cultivated in the San Joaquin Valley, cotton is the most significant in terms of pesticide usage. In Kern County, the cotton acreage harvested in 1965 was 171,700 acres which represented 26 percent of the total acreage harvested in that County. Pesticide usage on cotton in Kern County in 1965, however, accounted for more than 53 percent of the acreage treated by commercial pest control operators. Present pesticide use is most extensive in this area and will probably continue to receive the heaviest treatment in the future, as shown in Figure 19.

The five most frequently used pesticides in Kern County in recent years are listed in Table 14. Examination of this information shows a trend toward decreased usage of the chlorinated hydrocarbon compounds, and an increase in the use of thiophosphate and carbamate compounds. This trend is also observed for crops other than cotton. It is in agreement with production and marketing information available from pesticide manufacturers and with records of pesticide accident occurrence throughout the United States. Federal requirements placed on maximum DDT residues in milk have had a definite influence on reducing the use of this chlorinated hydrocarbon compound on hay and fodder crops and in fields adjacent to where these are grown. General restrictions on the use of chlorinated hydrocarbons on Federal lands have likewise reduced the use of these compounds.

These trends are significant since chlorinated hydrocarbon compounds, such as DDT and Toxaphene, are quite resistant to biochemical degradation and would be expected to be found more frequently in tile drain waters. Analyses of tile drainage from several fields in the San Joaquin Valley show that this is the case (Table 15). Chlorinated hydrocarbons were detected in almost all of the samples while the thiophosphate compounds were found only in about one-fifth of the samples. This finding may be attributed in large part to the greater biodegradability of the thiophosphate compounds which permits their destruction during passage through the soil.

TABLE 14

PESTICIDE USE ON COTTON
KERN COUNTY

Rank	1955	1960	1965
1	DDT (C)	ENDRIN (C)	ARAMITE (C)
2	SYSTOX (P)	DDT (C)	DYLOX (P)
3	TOXAPHENE (C)	ARAMITE (C)	TEDION (C)
4	ALDRIN (C)	TOXAPHENE (C)	AZODRIN (P)
5	ARAMITE (C)	TEDION (C)	SEVIN (B)

Type of Pesticide: (C) Chlorinated hydrocarbon, (P) Thiophosphate, (B) Carbamate

Source of data: Kern County Agricultural Commission

Pesticide application practices are continually being improved, primarily to reduce costs, to adhere to an increasing number of legislative restrictions, and in response to increasing public concern over detrimental effects to fish and wildlife. Soil injection techniques and fog aerial spraying are recent examples of application practices which result in better control of pesticide additions to the environment. Further improvements can be expected that will tend to reduce the amount of pesticide necessary to accomplish effective pest control.

Many complicating factors prevent any highly accurate estimate of the pesticide content of the Master Drain discharge. New compounds will undoubtedly be used, changes in crop patterns and pesticide application may develop, and some changes in pesticide content can be expected during the time of travel in the Master Drain to the point of discharge. However, reasonable estimates of the pesticide content of tile drainage to be collected by the Master Drain in the future can be based on past experience as summarized in Table 15 and the observed trends in the use of pesticides as described above. On this basis, the future concentrations of chlorinated hydrocarbons can be expected to be lower than those experienced in the past. The replacement of these compounds by more degradable types should result in an overall decrease in total pesticide content of tile drain waters in the future.

TABLE 15

PESTICIDES IN IRRIGATION DRAINAGE
(1963-1966)

Pesticide Compounds 1/	Sub-surface Tile Drainage			Surface Drainage		
	Concentration, µg/1			Concentration, µg/1		
	Mean	Peak	% 2/	Mean	Peak	% 2/
Chlorinated Hydrocarbons						
(No. of Analyses)			(78)			(64)
DDT-DDD	<.075	.600	96	<0.520	5.700	92
Toxaphene 3/	<.115	.950	17	1.870	6.600	100
DDE	<.030	.130	54	< .040	.150	22
Heptachlor Epox.	<.030	.045	54	< .030	.100	9
Lindane	<.035	.340	54	< .040	.240	16
Dieldrin	<.035	.130	30	< .030	.120	3
Thiophosphates						
(No. of Analyses)			(64)			(60)
Parathion	<.064	.160	6	< .206	3.600	33
Malathion	<.064	.195	6	< .066	.320	13
Baytex	<.064	.300	6	< .063	.160	9
Ethion	<.063	.230	2	< .100	1.200	20

1/ The detectable limit for chlorinated hydrocarbons and thiophosphates were established at 0.030 and 0.060 µg/1, respectively. Other compounds detected but in three samples or less:

Endrin
CIPC
PCNB
Chlordane
TCNB
Genite
Methoxychlor
BHC
Aldrin
Randox
Perthane
Methyl Parathion
Trithion
Thiodan
Dacthal
Simazine
Stam
Aramite
Heptachlor
Simazine
Disyston
Atrazine
Tedion
Thimet
Diazinon

2/ % = percent of samples in which detected.

3/ Presumptive

Source of Data: California Department of Water Resources and Federal Water Pollution Control Administration

The pesticide content of Master Drain waters will be significantly affected by the amount of surface drainage or tailwater which is collected. Tailwater is irrigation water that does not percolate into the soil, but runs off the land as surface drainage. As shown in Table 15, tailwater contains considerably higher concentrations of pesticides, as much as an order of magnitude higher, than tile drainage. This surface drainage contains substantial amounts of silt which readily adsorb pesticides, while subsurface tile drainage is free of silt and turbidity.

According to present plans the San Joaquin Master Drain will carry primarily sub-surface tile drainage [34]. Surface drainage is expected to amount to approximately 25 percent of the total flow initially and will become a progressively smaller fraction in subsequent years.

Pesticide concentrations in the Drain can be minimized by exclusion of surface drainage. Since these tailwaters are generally equivalent in mineral quality to the applied irrigation water they can, and indeed should, be reused for irrigation purposes. By such reuse this source of waste flow can be substantially eliminated. Though these waters would ultimately require disposal as sub-surface drainage they would be greatly reduced in volume due to consumptive losses by evapotranspiration. In addition, their pesticide and phosphorus content would be greatly diminished by adsorption on the soil through which they would percolate and by other processes such as biological degradation.

Delta

Most of the cultivated land on Delta islands lies below the water level in Delta channels. Irrigation is accomplished by diverting water from the channels (through siphons over the levees) into deep drainage ditches around the edge of the field and/or into deep "spud" ditches located at 50 to 90 foot intervals across the fields. In all cases, irrigation is accomplished by capillary movement of water upward from the water table into the root zone, and not laterally from the ditches as is often supposed. The salts which move upward with the irrigation water into the root zone by capillary action, remain there when the water is removed by evapotranspiration. These accumulated salts must be removed periodically by leaching which is usually carried out during the winter months.

Soils in the Delta are largely composed of peaty materials which are deficient in phosphorus but have sufficient quantities of available nitrogen. Typical fertilizer applications average 15 to 20 lbs/acre/year of phosphorus and only 5 lbs/acre/year of nitrogen.

The quality and seasonal distribution of Delta irrigation waste water reflect existing agricultural practice. Total dissolved solids in return flows are generally higher during winter months than during summer months [5]. Nitrogen concentrations are relatively low, i.e. from 0.6 to 2.1 mg/l as organic nitrogen and from 0.5 to 2.5 mg/l in the form of nitrate-nitrogen [32].

Irrigation diversions and waste water discharges were estimated primarily on the basis of data reported by the California Department of Water Resources. These data show that the salt content of Delta irrigation waste water, at any given time of the year, depends upon the quality of water applied and the degree of salt storage or salt leaching that has taken place in the soil. These factors were analyzed and appropriate relationships developed which would allow seasonal changes in waste water quality to be estimated for each of the Delta islands. Because of these variables, the waste load from Delta agricultural uses is not shown in the summary (Table 18) but is included in all subsequent analyses.

QUALITY OF TRIBUTARY STREAMS

Present

Current water quality data was used to establish the contribution of total dissolved solids, chlorides, total nitrogen, phosphorus and BOD by streams tributary to the Delta. The major contributions in terms of pounds per day are made by the Sacramento and San Joaquin Rivers. The quality data was adjusted to reflect median stream flow conditions for present upstream development by establishing a relationship between stream flow and pollutant load in pounds per day. The resulting "design" quality inflow for the Delta tributary streams in a typical July and January is presented in Table 16. Because of the relatively small contribution of streams tributary to the eastern Delta, they have been combined in the table as "Eastern Streams" and include the Cosumnes, Mokelumne, and Calaveras Rivers and Dry Creek.

Future

The future quality of tributary streams was estimated by modifying present stream flow versus rate of discharge curves for total dissolved solids, chlorides, total nitrogen, and phosphorus for future hydrology in a "median" year. The BOD was estimated based on future waste discharges and decay of the waste in transport. Design stream flow and quality for median July and January conditions are summarized in Table 16.

Storm Runoff

Waste loads contained in storm runoff from urban and rural areas were estimated, for January conditions, using mean monthly rainfall and appropriate runoff coefficients. The resulting concentrations of pollutants in storm runoff are presented below in Table 17.

Urban and rural runoff for January conditions, present, 1990 and 2020 are estimated to be 1000, 1300 and 1700 cubic feet per second, respectively. The areas included in the above estimates were directly tributary to San Pablo and Suisun Bays and the western edge of the Delta.

TABLE 16

DESIGN QUALITY OF TRIBUTARY STREAMS

	Sacramento River			San Joaquin River			Eastern Streams		
	Present	1990	2020	Present	1990	2020	Present	1990	2020
July Condition									
Flow, CFS	10,968	15,584	18,887	902	1,407	1,301	309	1,284	1,284
TDS, mg/l	123	128	135	684	496	500	139	496	575
Cl, mg/l	14	13	13	166	140	141	14	140	163
N, mg/l	0.3	0.4	0.7	1.0	1.8	3.5	0.3	1.0	1.0
P, mg/l	0.07	0.12	0.23	0.25	0.55	1.37	0.07	0.16	0.16
BOD, mg/l	0.8	1.0	1.4	2.2	3.1	7.1	0.8	3.6	3.6
January Condition									
Flow, CFS	21,509	13,356	13,947	2,228	2,829	2,439	1,138	618	618
TDS, mg/l	88	107	106	308	274	334	88	274	334
Cl, mg/l	8	10	12	86	83	106	8	83	106
N, mg/l	0.3	0.4	0.8	1.0	1.4	2.4	0.3	1.0	1.0
P, mg/l	0.07	0.13	0.29	0.16	0.33	0.82	0.07	0.16	0.16
BOD, mg/l	0.8	1.0	1.7	1.2	1.8	4.0	0.8	1.2	1.2

TABLE 17

DESIGN QUALITY FOR STORM RUNOFF
JANUARY CONDITION

	URBAN	RURAL
TDS, mg/l	150	85
Cl, mg/l	20	15
N, mg/l	3.0	1.0
P, mg/l	0.36	0.16
BOD, mg/l	25	10

SUMMARY OF WASTE WATER INPUTS

Waste loads used in determining the combined effects of municipal, industrial and agricultural wastes, include only discharges tributary to San Pablo and Suisun Bays and the Delta. The distribution of waste loads are based on an analysis of present and future land use. Waste load inputs for municipal and industrial discharges, the San Joaquin Master Drain and for tributary streams, including the Sacramento, San Joaquin and Eastern Streams are summarized in Table 18.

The distribution of nitrogen waste loads within the study area is presented in Figure 20. The nitrogen waste load from the San Joaquin Drain, for future summer conditions, is expected to equal or slightly exceed the nitrogen waste loads from all other sources tributary to San Pablo and Suisun Bays.

TABLE 18

SUMMARY OF DESIGN WASTE INPUTS[1/]
SAN PABLO BAY, SUISUN BAY, AND THE DELTA
SUMMER CONDITIONS

	Discharge	Thousands of Pounds Per day				
	Cu.Ft./Sec.	BOD	N	P	Cl	TDS
		Present				
Municipal	166	147	24.3	8.7	86	496
Industrial	49	168	33.1	0.4	549	1,803
San Joaquin Drain	-	-	-	-	-	-
Tributary Streams	12,180	59	13.1	5.5	1,661	10,842
TOTALS	12,395	374	70.5	14.6	2,296	13,141
		1990				
Municipal	603	189	58.6	25.8	340	1,742
Industrial	312	85	48.2	1.0	2,037	8,210
San Joaquin Drain	741	8	84.1	0.4	3,000	13,900
Tributary Streams	18,274	133	54.1	15.4	3,120	17,960
TOTALS	19,930	415	245.0	42.6	8,497	41,812
		2020				
Municipal	1,204	377	117.2	53.3	689	3,498
Industrial	448	128	62.1	1.6	2,998	12,190
San Joaquin Drain	1,018	11	115.3	0.6	3,680	13,700
Tributary Streams	21,472	218	103.0	34.2	3,450	21,280
TOTALS	24,142	734	397.6	89.7	10,817	50,668

[1/] A portion of the flows and waste loads shown for tributary streams will not enter the Bay-Delta system in the future due to planned transfer via the Peripheral Canal. This has been taken into account in subsequent analyses of the effects of waste discharges on the Bay-Delta system.

VII. EXISTING WATER QUALITY

The information developed in the preceding sections was used to predict future water quality conditions in the Bay-Delta system and the effect on those conditions of the discharge of San Joaquin Master Drain waters. In order to provide a proper baseline for the evaluation of future conditions, existing water quality characteristics and problems are discussed below.

GENERAL

The present quality of the waters of the San Francisco Bay-Delta system is generally adequate in most respects to support the many uses which it is capable of serving. A very general characterization of these waters (excluding south San Francisco Bay) is given in Table 19 for typical summer conditions. These figures show the normal gradual increase from the mouth to the head of an estuary of such quality indicators as temperature, suspended solids, and dissolved silica with the reverse being true for chlorides and transparency of the water. Constituents related to the biological enrichment of the waters such as nitrogen, phosphorus, chlorophyll and plankton counts all exhibit higher levels in Suisun Bay where the transition from a fresh to a brackish water environment takes place. This is normally the most biologically productive part of an estuary, but in this case also reflects the significant contribution of waste effluents entering the Bay in this area.

Data presented for the Eastern Delta generally reflects the relative quality of the two major tributary streams, the Sacramento and San Joaquin Rivers. In every respect the quality of the Sacramento River exceeds that of the San Joaquin River.

WATER QUALITY PROBLEMS

The quality of San Francisco Bay and Delta waters has generally improved over the past fifteen years. This improvement has been brought about by the large expenditures made in providing treatment facilities for both municipal and industrial waste sources. But while evidences of gross pollution have been largely eliminated, the extremely rapid recent growth in the tributary area population and industrial activity has left some problems unsolved and created some new ones.

TABLE 19

TYPICAL SUMMER QUALITY CONDITIONS
SAN FRANCISCO BAY-DELTA SYSTEM

	North San Francisco Bay	San Pablo Bay	Suisun Bay	Western Delta	Eastern Delta- Sacramento R. @ Walnut Grove	Eastern Delta- San Joaquin R. Below Mossdale
Temperature, °C	15±2	18±2	19±2	21±3	20±2	24±2
Suspended Solids, mg/l	10	40	50	40	35	80
Transparency,[1/] ft.	5.0	1.5	1.0	1.0	3.0	0.5
Chloride, g/l	16+2	12+2	5±2	1±1	0.1	0.2
Total Nitrogen, mg/l	0.7	0.9	1.3	0.9	0.7	2.5
Total Phosphorus, mg/l	0.1	0.1	0.2	0.1	0.1	0.2
Dissolved Silica, mg/l	3±1	4±3	5±4	10+2	20+2	35+5
Dissolved Oxygen, mg/l	8±1	8±1	8±2	8±2	8±1	7±7
Pesticide,[2/] μg/l	0.15	---	0.3	0.2	0.25	0.4
Chlorophyll, μg/l	5	10	30	20	---	100$^+$
Plankton Count, 1000/ml	1	2	15	10	3	30$^+$

1/ Secchi Disc

2/ Sum of identified chlorinated hydrocarbons and thiophosphates.

The existing water quality problems of the Bay-Delta system may be categorized by 1) eutrophication and associated dissolved oxygen deficiencies, 2) suspended sediments and turbidity, 3) salinity, 4) toxic materials, and 5) bacteriological quality.

Eutrophication

Problems resulting from nutrient enrichment and associated periodic dissolved oxygen depression are numerous in the Bay-Delta area.

Delta. The most serious enrichment problems in the Delta are found along the San Joaquin River and in certain localized areas receiving waste discharges but having little or no net fresh water flow. These problems occur mainly in late summer and coincide with low river flows, high temperatures and the harvesting season when fruit and vegetable canneries are in full operation.

During summer months the San Joaquin River is essentially a waste drain enriched by agricultural, municipal and industrial wastes. The river is extremely turbid as a result of silt accompanying irrigation drainage and high algal populations resulting from enrichment.

Salmon runs up the San Joaquin River and tributaries once exceeded 100,000 fish. Upstream dam construction with resulting flow reductions and loss of upstream spawning grounds have greatly reduced the size of the San Joaquin salmon run. The remnants of the fall salmon run into the San Joaquin River system face extinction as a result of a "pollution block" in the vicinity of Stockton. Low autumn river flows combined with seasonally high organic waste loads (canneries) have created environmental conditions unsuitable for passage of anadromous fish from the southeastern Delta to the San Joaquin Valley streams. Reverse salinity gradients (related to low fresh water inflows and the salts present in agricultural drainage) and low dissolved oxygen concentrations (related to high respiratory activity of algae and organic waste decomposition) are major factors contributing to the blockage of autumn salmon migrations.

Deep water ship channels create localized areas where low dissolved oxygen levels can occur more easily. Atmospheric reaeration and photosynthetic oxygenation may be exceeded by biological respiration in deep turbid channels making these waters a poor habitat for desirable aquatic species. The ship channel below Stockton is an example of what can happen when community respiration is high in a deep, poorly-mixed channel. Here, dissolved oxygen levels become low enough to result in one or more fish kills almost every summer.

Warm, shallow, dead-water areas of the eastern Delta support extremely dense (as high as 600,000 cells/ml) populations of planktonic blue-green algae during summer months. Channels supporting water contact recreation have contained water bright green with algae during late summer. Of the many algal forms, the blue-greens are most frequently associated with nuisance conditions such as taste and odors in water supplies, obnoxious odors resulting from decaying cells, and excretion of toxins harmful to animal life. Blue-green algae are also a poor food source for higher aquatic life.

Floating and semi-attached aquatic plants such as water primrose and water hyacinths frequently clog waterways in the San Joaquin River system during the summer. Extensive growths of these plants have also been observed in localized waterways of the Delta. These plants interfere with the passage of small boat traffic and contribute to the total organic load in the Delta-Bay system as they break loose and move downstream in the fall and winter months.

Dense populations of the Asiatic clam (Corbicula fluminea) clog intake screens at the Tracy Pumping Plant and reduce the hydraulic capacity of the South Bay Aqueduct, the Delta-Mendota Canal and other canals in the San Joaquin Valley. Control of the clam nuisance is expensive. Recently $10,000 was required to clean a two-mile reach of the Delta-Mendota Canal near its headworks.

San Francisco Bay. Enrichment problems in San Francisco, San Pablo and Suisun Bays are located mainly along shorelines and in the tidal reaches of certain tributaries to the bays. Depressed and widely fluctuating dissolved oxygen levels occur in the turbid waters of the Napa and Petaluma River estuaries (tributary to San Pablo Bay) and in tidal waters of Coyote Creek (tributary to south San Francisco Bay). Differences between near surface and near bottom dissolved oxygen (DO) levels have exceeded 20 mg/l and levels sufficiently low to be critical to aquatic life are frequently found. Decomposition of treated domestic and industrial wastes and respiration of planktonic plants are mainly responsible for the low DO levels. In addition, fluctuations in pH and higher than normal pH values (8.5-9.5) occur as a result of algal activity.

Bay tide flats support birds, fish and food organisms important to the entire Bay community. Filling activities have displaced wildlife, destroyed habitats for fish and food organisms, and reduced the volume of the tidal prism. Shallow well-mixed tidal areas such as Grizzly and Honker Bays play a vital role in maintaining healthy dissolved oxygen concentrations in adjacent deeper areas.

Several extensive real estate developments have been constructed around the Bay shorelines which provide residents with access to the Bay through man-made tidal lagoons. Some of these developments have resorted to the use of algicides to maintain water clarity.

Barnacles and other fouling organisms are most prevalent in enriched marine areas of the Bay. A recent survey of operators of boat yards has indicated that hull maintenance is more frequent in enriched areas than in other areas of the Bay.

Stranded green seaweeds (Ulva and Enteromorpha) have produced strong odors and blackened lead base paints at several points around the shores of San Francisco Bay. Mats of decomposing green seaweeds have reached nuisance proportions in the Albany tide flat in the vicinity of a sewage treatment plant outfall. Extensive mats of Enteromorpha were observed in two somewhat more highly enriched bays (Bolinas and Bodega) along the Pacific coast during the summer of 1966.

Discoloration of Bay waters due to green algal populations and due to the red-pigmented marine ciliate, Mesodinium, has raised concern among fishermen and shoreside property owners.

It is clear that eutrophication of Bay and Delta waters due to enrichment by nutrient materials is already a problem of serious proportions in some confined channels and shoreline locations and could become a significant factor affecting the quality of the entire estuary.

Suspended Sediments

Much of the water in the Bay-Delta system is turbid as a result of an abundance of suspended silts and clays, particularly in Suisun Bay, the Delta, the San Joaquin River, and various smaller tidal streams. Most of these sediments enter the tidal system with the flow of the major tributary rivers. Some enriched areas are also turbid as a result of planktonic algal populations.

Continuous dredging operations to maintain deep channels for shipping has contributed to turbidity of Bay waters and has been a significant, but as yet unquantified, factor in the destruction of bottom organisms through displacement and suffocation.

Suspended sediments and pollution have been linked with the eradication of the native Bay oyster fishery which flourished in the 1890's. The oyster industries of the past century were apparently lost due to siltation from upstream mining operations. Evidence of the oysters' former prominence is found in the dense deposits of oyster shells which are now mined commercially by the cement industry in south San Francisco Bay.

Salinity

Municipal, industrial, and agricultural water supplies are derived from waterways of the western Delta and eastern Suisun Bay. Due to salinity incursion, many of these supplies must be abandoned for other more expensive sources during the summer low-flow period.

Desirable wildfowl plant and seed food sources in Suisun Marsh require fresh waters; salt tolerant plants (pickleweed, salt grass) are inferior as food sources. Increased salinities in Suisun Marsh have reduced the productivity of the marsh as an important wildlife feeding area of the Pacific Flyway. Management practices to compensate for this reduced productivity are currently under study.

Increased salt concentrations in the southeastern Delta, particularly along the San Joaquin River, result mainly from irrigation return flows. Levels approaching 1000 mg/l total dissolved solids (TDS) are not uncommon and have a detrimental effect on further irrigation use and on the Delta fishery. Increases in TDS concentrations result in increased operating expenses to the farmer because of the need to leach accumulated salts from the soil at more frequent intervals. The California Department of Fish and Game reports that striped bass will avoid spawning in areas where salts exceed 350 mg/l TDS. There is also evidence that reverse salinity gradients in the San Joaquin River have been a factor in reducing fall salmon spawning migrations.

Toxic Materials

Fish kills caused by toxic waste discharges have occurred at various times. Industrial wastes have killed large numbers of fish in localized areas in the Bay, and agricultural pesticides have been responsible for fish kills in the Delta and Central Valley. The majority of these kills were the result of accidental spills or discharges.

Large numbers of striped bass and other fishes have died during late spring and early summer for many years. No similar striped bass mortalities have been observed in other estuaries around the country. The cause or causes are as yet unknown but seasonal changes in water quality and toxic pollutants are suspected.

Pesticides are found throughout the waters and bottom sediments of the Bay-Delta system. Summaries of concentrations found in waters and sediments during the past three years are presented in Tables 20 and 21, respectively. The more persistent chlorinated hydrocarbon pesticides are uniformly found throughout the system at a higher level than the less persistent organophosphate compounds. The sediments having the highest pesticide content are found in the western Delta and in the bays seaward of that point. The compound DDT was predominant in all samples.

Pesticides are found in aquatic life of the Bay and Delta in relatively high concentrations when compared with levels found in their surrounding waters. For example, concentrations of total chlorinated hydrocarbons in the whole bodies of small fishes (less than twelve inches in length) average 300 ppb (parts per billion) while the concentrations in the surrounding waters are approximately one thousand fold less. Average

TABLE 20
PESTICIDE CONCENTRATIONS IN SAN FRANCISCO BAY AND DELTA WATERS
(1963 - 1966)(μg/1)

Pesticide Compounds1/	Eastern Delta						Western Delta			Bay Waters		
	San Joaquin R. @ Vernalis			Sacramento R. @ Walnut Grove			San Joaquin R. @ Antioch			Suisun Bay @ Martinez		
	Mean	Peak	%2/	Mean	Peak	%2/	Mean	Peak	%2/	Mean	Peak	%2/
Chlorinated Hydrocarbons												
(No. of Analyses)			(109)			(113)			(68)			(36)
DDT-DDD	<.070	.400	82	<.055	.200	75	<.058	.170	94	<.051	.200	83
Toxaphene3/	<.100	.930	32	<.040	.400	16	<.037	.320	6	<.049	.600	11
DDE	<.032	.100	41	<.032	.100	46	<.030	.050	47	<.034	.100	45
Heptachlor Epox.	<.032	.065	34	<.030	.040	48	<.030	.050	56	<.033	.150	53
Lindane	<.031	.070	33	<.030	.070	32	<.032	.100	47	<.031	.040	50
BHC 3/	<.030	.070	6	<.030	.100	9	<.031	.080	3	<.030	<.030	6
Dieldrin	<.032	.075	13	<.032	.150	16	<.033	.100	9	<.030	<.030	11
Heptachlor	<.030	<.030	4	<.030	.040	5	<.030	<.030	0	<.030	<.030	0
Thiophosphates												
(No. of Analyses)			(60)			(52)			(49)			(25)
Parathion	<.060	13.9	5	<.060	5.08	4	<.060	5.30	4	<.068	.260	4
Malathion	<.060	.120	8	<.060	.080	10	<.060	.080	6	<.060	<.060	16
Baytex	<.060	1.20	10	<.060	<.060	4	<.060	<.060	10	<.060	<.060	0
Ethion	<.060	<.060	10	<.060	<.060	2	<.060	<.060	2	<.060	<.060	8

1/ The mean detectable limits for chlorinated hydrocarbons and thiophosphates were established at 0.030 and 0.060 ug/1, respectively. Other compounds detected but in three samples or less:

Endrin	TCNB	Aldrin	Trithion	Simazine	Tedion	Delnav	Chlordane
CIPC	Genite	Randox	Thiodan	Stam	Disyston	Thimet	Methyl Parathion
PCNB	Methoxychlor	Perthane	Dacthal	Aramite	Atrazine	Diazinon	

2/ % = Percent of samples in which detected.

3/ Presumptive

Source of Data: California Department of Water Resources

TABLE 21

CHLORINATED HYDROCARBON PESTICIDES IN BOTTOM SEDIMENTS OF SAN FRANCISCO BAY AND DELTA
(1965 - 1966)(μg/kg Dry Wt.)

Chlorinated Hydrocarbons1/	Eastern Delta						Western Delta			Bay Areas					
	San Joaquin R. @ Vernalis			Sacramento R. @ Walnut Grove			San Joaquin R. @ Antioch			Suisun Bay @ Martinez			San Pablo Bay @ Pt. San Pablo		
	Mean	Peak	%2/	Mean	Peak	%2/	Mean	Peak	%2/	Mean	Peak	%2/	Mean	Peak	%2/
(No. of Analyses)			(10)			(11)			(16)			(16)			(15)
DDT-DDD	<18	59	90	56	120	100	107	370	100	165	1372	100	67	285	100
DDE	< 4	10	80	<14	39	91	< 22	93	75	<23	83	81	<11	32	80
Heptachlor Epox.	< 6	32	70	< 8	24	64	< 29	79	81	<18	60	81	<10	36	67
Dieldrin	< 2	10	20	< 2	9	36	< 12	100	44	<16	74	75	< 4	21	47
Lindane-BHC	< 1	3	20	< 3	11	45	< 26	99	62	< 9	49	69	< 6	21	47
CPC/TCNB/PCNB	<18	170	10	< 1	<1	0	< 68	410	44	< 5	42	12	< 5	38	13
Toxaphene3/	< 1	<1	0	<16	130	18	< 10	140	6	< 1	< 1	0	< 8	110	7
Endrin	< 1	<1	0	< 1	5	10	< 1	< 1	0	< 2	16	2	< 1	< 1	0

1/ Mean limit of detection was established at 1.0 ug/kg. Other compounds looked for but not detected:

Chlordane	Methoxychlor	Randox	Trithion	Dacthal	Stam	Tedion
Genite	Aldrin	Atrazine	Thiodan	Simazine	Aramite	Perthane

2/ % = Percent of samples in which detected.

3/ Presumptive

Source of Data: California Department of Water Resources.

concentrations found in certain organs of large fish, such as the brain, liver, reproductive organs and visceral fat are higher, ranging from 200 to 68,000 ppb. The large difference in concentration between fish and water is apparently due to biological magnification through the food chain although there is recent evidence to indicate that fishes can also accumulate pesticides by direct absorption from the water environment. Pesticide residues found in apparently healthy aquatic biota of San Francisco Bay and Delta are summarized in Table 22.

The long term effects of pesticide concentrations found in aquatic life of the Bay and Delta are not known. The effects of intermittent exposure to toxic pesticide levels in water and of long term exposure to these compounds and combinations of them are likewise unknown. Variations in species sensitivity complicate an evaluation of the pesticide threat.

Bacteriological Quality

Bacteriological quality of Bay-Delta waters as measured by the presence of coliform bacteria varies depending upon proximity of waste discharges and significant land runoff. Generally speaking, the highest concentration of coliform organisms are found in the western Delta and progressively decrease toward the Golden Gate. Local exceptions to this can be found in the vicinity of major municipal waste discharges. Most of Suisun and San Pablo Bays and localized areas of San Francisco Bay presently exceed 1000 coliforms per 100 ml over 20 percent of the time, the quality level prescribed by the California Department of Public Health for water contact sports. Chlorination of municipal waste effluents will be a general practice in the near future as a result of recent action by the San Francisco Bay Regional Water Quality Control Board which recognizes water contact sports and shell fishing as beneficial water uses to be protected. At the present time, the harvesting of shellfish from Bay waters for human consumption is practically non-existent due to bacterial contamination.

TABLE 22

OCCURRENCE OF PESTICIDES IN APPARENTLY HEALTHY AQUATIC BIOTA OF SAN FRANCISCO BAY AND DELTA

1963-1966

(Total Identified Chlorinated Hydrocarbons in ppb)

Biota or Organ	Small Fish 1/	Large Fish		
		Sturgeon	Striped Bass	Salmon
Fish Organs				
Brain	4285(8) 2/ 250-8320	26,700(6) 6257-48,810	28,747(3) 2050-40,650	272(3) 195-351
Fat	65,902(190) 20-275,200	12,260(6) 3613-33,660	35,732(42) 17,205-68,010	3597(5) 1000-6840
Liver	117(15) 60-180	13,530(6) 4541-23,141	8,972(7) 2260-13,030	1445(3) 1276-1584
Gill	290(1)	3395(6) 485-7048	1830(3) 1238-2877	902(3) 748-986
Kidney	---	2950(6) 930-5330	2610(3) 940-5934	154(3) 68-214
Flesh	1353(72) 42-6260	2580(6) 732-6964	483(6) 300-1008	2448(16) 340-7214
Blood	---	515(6) 86-2235	466(7) 151-783	133(4) 40-342
Whole Fish	804(158) 160-1800		686(2) 257-1114	273(1)
Shrimp	148(10) 61-356			
Oysters	144(72) 9-321			
Plankton	30(1)			

Source of Data: California Dept. of Fish & Game
University of California
Federal Water Pollution Control Administration

1/ Includes catfish, trout, large-mouth bass, carp, black crappie, English sole, northern anchovy, shiner perch, and others less than approximately twelve inches in length.

2/ Read as:

Mean — No. of Analyses
4285(8)
250 - 8320
Range

VIII. PREDICTION OF FUTURE WATER QUALITY

BASIS FOR ANALYSIS

Future water quality conditions in the Bay and Delta will be determined by the input of pollutants and water to the system. In Chapter VI the input of pollutants from all significant sources was projected for the years 1980, 1990, and 2020. The inflow from tributary streams expected to exist at those times was obtained from projections prepared by the Bureau of Reclamation for this study [1]. This design hydrology is presented in Table 23 and represents a median year condition. The design hydrology incorporates water resource developments planned for the future, the most significant being the large projected export diversions from the Sacramento River and the implementation of plans for a Peripheral Canal. As a result of these diversions, the net Delta outflow in the median year will drop significantly in the future and will reach a controlled minimum value of 1500 cfs for the July condition by 1990. By the year 2020, both the January and July flows in the median year will be at the minimum controlled level of 1500 cfs. This minimum controlled Delta outflow of 1500 cfs is used by the Bureau of Reclamation as the minimum flow necessary to prevent intrusion of brackish water from Suisun Bay.

PLANS EXAMINED

Several alternate plans were examined for disposal of Master Drain waste waters to the Bay-Delta system. The following discharge locations were considered:

Plan 1. Drain discharge to San Joaquin River near Antioch
Plan 2. Drain discharge to Suisun Bay near Middle Point
Plan 3. Drain discharge to San Pablo Bay near Rodeo
Plan 4. No drain discharge to the Bay-Delta system

Certain options in Delta outflow as shown below were considered. One or more of these was examined in conjunction with the above plans:

Option A. Delta outflow, 3508 cfs (July present)
Option B. Delta outflow, 25,609 cfs (January present)
Option C. Delta outflow, 3300 cfs (July 1980)
Option D. Delta outflow, 1500 cfs (July 1990)
Option E. Delta outflow, 3000 cfs (July 1990)
Option F. Delta outflow, 6000 cfs (July 1990)
Option G. Delta outflow, 6650 cfs (January 1990)
Option H. Delta outflow, 1500 cfs (July 2020)
Option I. Delta outflow, 3000 cfs (July 2020)

TABLE 23

HYDROLOGY USED IN MATHEMATICAL MODEL STUDIES

	Median Year Flows (cfs)					
	Present		1990		2020	
	Jan	Jul	Jan	Jul	Jan	Jul
Sacramento River	21,509	10,968	13,356	15,584	10,947	18,887
San Joaquin River	2,228	902	2,829	1,407	2,439	1,301
Eastern Streams	1,138	309	618	1,284	618	1,284
TOTAL	24,875	12,179	16,803	18,275	14,004	21,472
Net Delta Depletion	-978	4,561	-1,164	4,222	-2,179	3,818
Export Diversions	244	4,110	11,317	12,553	14,683	16,154
TOTAL	-734	8,671	10,153	16,775	12,504	19,972
Net Delta Outflow (Excluding the Drain	25,609	3,508	6,650	1,500	1,500	1,500

The Delta outflows shown above exclude any Drain discharge flow. Median monthly conditions were used in each case. However, in Options E and F, it was assumed that the additional flow was available from the Sacramento River, a portion of which was released from the Peripheral Canal. Not all options were examined for each plan because they either 1) were not appropriate to the plan under consideration or 2) were rejected as of little importance after the results of other plans and options had been examined.

METHODS USED

To make predictions of future water quality in the Bay and Delta a mathematical simulation, or model, of the system was developed and used [35, 36]. The model included the Delta, Suisun Bay and San Pablo Bay and yielded mean tidal concentrations of the pollutant being investigated at dynamic steady-state conditions for selected locations throughout the system. The time required for the waters in this area to reach steady-state is dependent upon numerous factors, but is of the order of one month at moderate flood flows (about 25,000 cubic feet per second) and up to one year for the buildup of constituents with a low rate of discharge to the estuary. Under future conditions of sustained controlled low outflow, receiving water concentrations should frequently approach or equal the steady-state concentration.

The distribution pattern for releases to Delta channels from the Peripheral Canal was selected to attain an objective of comparable TDS gradients in both the Sacramento River and the San Joaquin River in the western Delta. Other operating criteria might indicate different releases. The effect of this variable was not investigated.

The selection of water quality indicators for investigation was based on the expected quality of the Drain waters. Primary emphasis was placed on total dissolved solids (TDS) and total nitrogen. Biochemical oxygen demand (BOD), dissolved oxygen (DO) and several other constituents were also investigated.

Verification of the performance of the model was achieved by comparison with past salinity and hydrological conditions and with the results of a prototype dye tracer study. A description of this study is contained in the appendix to this report.

In these analyses, total nitrogen was treated as a conservative pollutant. A simulation of present nitrogen distributions in the Bay and Delta was carried out for average July conditions with the results as shown in Figure 24. The predicted distributions are very similar to the concentrations observed in the Bay and Delta during recent summers (Table 19), and in general, were the same or slightly higher than actual conditions.

The slight differences that were found can be attributed to 1) the present effectiveness of high winter flows in flushing accumulated nitrogen to the ocean, thus preventing the achievement of steady-state conditions, and 2) the removal of some nitrogen from the water as a result of uptake by attached aquatic plants, larger aquatic animals, etc. The principal characteristics of present nitrogen distributions in the Delta are portrayed with a satisfactory degree of accuracy. The high nitrogen concentrations consistently found in the San Joaquin River near Stockton, for example, are readily apparent from the model analysis.

PREDICTED QUALITY

Total Dissolved Solids

The effect of the Drain discharge at Antioch on the distribution of TDS in the Delta can be seen by comparison of Figures 21 (without the Drain) and 22 (with the Drain). These distributions are for the July 1990 level of development with the Delta outflow controlled at 1500 cfs. The total outflow for the condition with the Drain discharge (Figure 24) is 2241, i.e., 1500 cfs minimum controlled outflow plus the Drain discharge of 741 cfs.

At this level of outflow the addition of the Drain discharge does not adversely affect the TDS levels in the Delta. On the contrary, the Drain discharge has a beneficial effect. The TDS concentration at Antioch, for example, is 5800 mg/l with no Drain discharge and 3900 mg/l with the Drain discharge.

Of greater significance than any single location, however, is the mean TDS in water diverted by agricultural users in the Delta. This is a value obtained by averaging the concentrations found at agricultural water intake points in the Delta and weighting the average according to the amount of water diverted. The resulting mean value, thus provides a more accurate estimate of the impact of water quality variations on the agricultural water user.

This mean Delta TDS value was calculated to be 697 mg/l without the Drain and 606 mg/l with the Drain discharge, an improvement of 91 mg/l. A similar result was obtained for July 2020 conditions as shown in Table 24.

The results obtained using 1500 cfs for July 1990 conditions indicate that this flow may be an unrealistic one to use for two reasons: 1) the existing mean TDS of Delta diversions for July is 264 mg/l. An increase to 697 mg/l by 1990 would probably not be considered tolerable, and 2) the proposed "Delta water quality criteria" (see page 14) of 500 mg/l (monthly mean TDS) at Rio Vista and San Andreas Landing is not met at this outflow.

TABLE 24

INCREMENTAL EFFECTS OF THE MASTER DRAIN ON BAY-DELTA WATER QUALITY[1]

Delta Outflow [2] (cfs)	1500 July	1500 July	3000 July	6650 January
Drain Discharge Location	Antioch	Middle Pt.	Antioch	Antioch
Mean Total Nitrogen in Suisun Bay, mg/l				
1990	+2.8	+3.6	+4.1	+0.7
2020	+3.4	+3.9	+5.3	
Mean Delta Agricultural Water TDS, mg/l				
1990	-91	-97	+14	+13
2020	-96	-120		

---

[1] Each concentration value shown is the algebraic difference between the mean concentration expected at a given Delta outflow plus the Drain discharge and the mean concentration for the same Delta outflow without the Drain discharge (+ indicates increase due to Drain, - indicates decrease due to Drain).

[2] Excluding Drain discharge.

For these reasons higher Delta outflows were examined. At an outflow of 3000 cfs (3741 cfs, including the Drain discharge) the mean July 1990 TDS of Delta diversions was 373 mg/l with the Drain and 359 mg/l without the Drain. Thus, the effect of the Drain at this higher level of controlled outflow is no longer beneficial, but has a slight detrimental effect. However, the water quality objective at Rio Vista and San Andreas Landing is essentially met in both cases since the average TDS at these locations is 490 mg/l without the Drain discharge and 522 mg/l with the Drain discharge.

An examination of conditions with a 6000 cfs Delta outflow (6741 cfs, including the Drain discharge) indicated a mean TDS for Delta diversions of 319 mg/l in July 1990. This is somewhat higher than the existing mean TDS level of 264 mg/l which is achieved at a much lower outflow of 3508 cfs (median July conditions).

The effect of Delta outflow on the mean TDS of Delta diversions both with and without the Drain is shown in Figure 29 for July 1990. The difference between these curves, expressed as mean Delta TDS, is the effect of the Drain. A second plot in Figure 29 shows how this effect varies with Delta outflow. It is apparent that the Drain would have a beneficial effect at outflows of less than approximately 2800 cfs and a detrimental effect at higher controlled Delta outflows.

The effect of moving the Drain discharge point seaward was also studied. As shown in Table 24, a Drain discharge to Suisun Bay (Middle Point) has a slightly greater beneficial effect on the mean Delta TDS than the release at Antioch both in July 1990 and 2020 with a Delta outflow of 1500 cfs. Although movement of the Drain to Middle Point was not studied at higher outflows, it could be expected the Drain discharge would have a beneficial effect on TDS in the Delta at higher outflows as well, though this beneficial effect would become progressively smaller as the Delta outflow is increased.

Movement of the Drain discharge further west to San Pablo Bay (at Rodeo) results in an increase in mean Delta TDS. The value of additional outflow in controlling salinity intrusion in the Delta is apparently lost if the flow does not enter the Bay system east of Carquinez Strait.

Total Nitrogen

The discharge of the Master Drain at Antioch with a Delta outflow of 1500 cfs would result in high nitrogen concentrations in the western Delta and in Suisun Bay. The average nitrogen content of Suisun Bay would be raised 2.8 mg/l in 1990 and 3.6 mg/l in 2020 (Table 24). Moving the Drain discharge seaward to Middle Point would lower nitrogen concentrations in the Delta but increase them in Suisun Bay. The average nitrogen content of Suisun Bay would be raised 3.6 mg/l in 1990 and 3.9 mg/l in 2020 by the Drain discharging at Middle Point.

The distribution of nitrogen from a Drain discharge at Antioch was also investigated at a Delta outflow rate of 3000 cfs. Raising the outflow from 1500 to 3000 cfs reduces the nitrogen concentration in the Delta attributable to the Drain discharge but increases the mean concentration in Suisun Bay. At this higher outflow the average nitrogen content of Suisun Bay would be raised 4.1 mg/l in 1990 and 6.0 mg/l in 2020.

The distribution of nitrogen expected in the Bay and Delta in July 1990 is shown in Figure 27 for a 3000 cfs outflow and the Drain discharge at Antioch. Since the total outflow including the Drain would be quite similar to the present median July outflow, Figure 27 may be compared directly to Figure 24 which shows present conditions. This comparison reveals that a very large increase in nitrogen in Bay-Delta waters will occur by 1990. The portion of this buildup attributable to the Drain is shown in Figure 28.

Nitrogen conditions were also examined for 1980, approximately ten years after initiation of the Drain discharge. The distribution at 3300 cfs outflow and the Drain discharge at Antioch as shown in Figure 25 indicates that significantly large increases would occur by that early date. The increase attributable to the Drain in 1980 is shown in Figure 26.

Even without a Drain discharge, higher nitrogen concentrations can be expected in the Delta when the Peripheral Canal goes into operation. At that time, the very large quantities of nitrogen removed in water diverted at the Tracy pumps will remain in the Delta. Loss of this flushing flow will result in an immediate increase in nitrogen concentrations in the Delta.

Biochemical Oxygen Demand

Limited studies were undertaken to determine biochemical oxygen demand (BOD) distributions and dissolved oxygen (DO) concentrations for several plans. Calculations were based upon the ultimate oxygen demand of all wastes using the combined effect of ultimate nitrogenous and ultimate carbonaceous demands after treatment. Except for localized problem areas, BOD was typically low and the resulting dissolved oxygen depression not significant. As discussed later, the combination of BOD and the respiration of high algae concentrations can cause significant DO depressions.

Pesticides

Prediction of the effect of the Master Drain discharge on the pesticide concentration of Bay and Delta waters requires knowledge of both the pesticide concentration in the Drain discharge and that which would exist in the receiving waters in the absence of this discharge. As discussed in Chapter VI estimates of the pesticide content of the Drain discharge and receiving waters are complicated by periodic changes in pesticide usage by agriculture as the result of development of improved types of compounds, methods of application and other factors. Based on current conditions and observed trends, however, a reasonable estimate of effect of the Master Drain discharge on the pesticide concentration of Bay and Delta waters can be made.

It has been noted previously that over the past three years laboratory analyses for approximately 35 different pesticides have been performed on samples of tile drain water and of the waters of the San Francisco Bay and Delta. Most of these compounds were rarely detected in any of the samples. Approximately ten pesticides are used quite extensively and are sufficiently persistant that they can often be detected in both tile drainage and in Bay and Delta waters. For all but one of these compounds, however, the concentrations found in both types of samples are not detectably different. The only exception would appear to be the chlorinated hydrocarbon compound, Toxaphene. This pesticide was found in only 6 percent of the samples collected from the Delta at Antioch and 17 percent of the tile drain water samples. Its average concentration in tile drainage was approximately three times the concentration observed in the Delta at Antioch.

It has been noted previously that for a variety of reasons usage of chlorinated hydrocarbon pesticides such as Toxaphene is steadily declining. These compounds are being replaced by the less persistent thiophosphate and carbamate types of pesticides which, because of their biodegradability characteristics, disappear more rapidly from the environment. It is expected that this trend will continue and an accompanying drop in pesticide concentrations throughout the environment will gradually occur. On this basis it may be concluded that the concentration of pesticides in tile drainage collected by the Master Drain will not be significantly higher than the concentrations presently observed in the waters of the Delta. It follows, then, that the discharge of the Master Drain to the Delta would not result in concentrations significantly higher than those presently observed in these receiving waters.

This conclusion would not necessarily apply, however, if significant quantities of surface irrigation return waters were collected by the Master Drain. These waters contain much higher pesticide concentrations and if collected by the Master Drain would greatly increase the pesticide concentration of the Drain discharge. In this case an increase in present pesticide concentrations in the receiving waters would result. This could be prevented by prohibiting the entry of surface drainage to the Master Drain.

The pesticide concentration in the Master Drain discharge can also be controlled by imposing penalties or by requiring pre-treatment of tile drainage waters containing significant quantities of the persistent types of pesticides. The centralized collection and disposal of tile drain waters of the San Joaquin Valley thus offers an opportunity for control of pesticides in the environment that is presently not available.

Suspended Sediment and Light Penetration

Suspended inorganic sediment (silt and clay) concentrations in Bay-Delta waters are expected to decrease in the future [37]. The principal reasons are 1) reduction in sediment transport to the Delta due to diversion of Sacramento River water to the Peripheral Canal for export, 2) lessened effects of wind and tidal currents on resuspension due to stabilization of bottom sediments under sustained low outflow conditions, and 3) possible future requirements for physical removal of dredge spoils from the estuary for land or ocean disposal.

The estimated median annual sediment transport into the Bay-Delta system and the associated suspended sediment concentration for 1960 and those predicted for 1990 and 2020 conditions are presented in Table 25. The predicted inorganic suspended sediment concentrations are assumed to be in direct proportion to the sediment inflows.

The location in the Bay where incoming sediments flocculate and settle to the bottom is largely determined by salinity gradients. The more extensive intrusion of sea salts during periods of sustained low flow will probably result in the alteration of existing suspended sediment distributions and shoaling patterns in the Bay.

Light penetration estimates presented in Table 25 are based on predicted inorganic suspended sediments and the use of the Beer-Lambert Law [37, 38]. The tabulated values for depth of the euphotic zone represent the depth at which surface light is reduced to 1 percent of its incident value. The euphotic zone defines the volume of water where photosynthesis can take place.

TABLE 25

SEDIMENTS AND LIGHT PENETRATION

Year	Median Annual Sediment Transport (10^6 Tons)	Suspended Sediment mg/l		Depth of Euphotic Zone (ft)	
		San Francisco Bay	Suisun Bay	San Francisco Bay	Suisun Bay
1960	2.6	10	50	14	3
1990	0.7	3	14	50	10
2020	0.4	2	8	70	20

Future increases in water transparency due to reduction of suspended inorganic sediments will permit light energy to penetrate much deeper into Bay waters than at present. This enlargement of the euphotic zone will, in turn, permit the growth of greater algal populations which themselves create turbidity. The overall net effect on water transparency will depend on the nutrient level, water temperature, and other factors related to growth of algae.

Temperature

Fresh water flows into and through the Delta will be significantly decreased in future years due to the operation of the Peripheral Canal. While this could bring about a slight increase in summer water temperatures in the northeastern Delta and slight decreases at points where water is released from the Peripheral Canal, these changes are not considered to be significant to overall water temperature conditions in the Delta. In evaluating future water quality conditions, therefore, it has been assumed that existing Delta water temperatures would prevail in the future.

IX. EFFECTS OF PREDICTED QUALITY ON WATER USES

The changes in Bay-Delta water quality caused by the discharge of the San Joaquin Master Drain at Antioch will have significant effects upon existing and future uses of these waters. These effects have been evaluated and estimates made, where possible, of their economic consequences. The uses considered were agriculture, municipal and industrial water supply, fisheries, shoreline residential development, boating and navigation, recreation and aesthetics, and wildlife propagation.

MUNICIPAL AND INDUSTRIAL USES

As described earlier, water resources development projects planned or under construction in the Central Valley will result in a significant decrease in Delta outflow and an increase in salinity incursion in the future. This will essentially terminate existing diversions from the western Delta waterways for municipal and industrial process water supplies because of high salinity. To compensate for this loss, the Bureau of Reclamation and California Department of Water Resources have proposed alternate overland supplies of high quality water diverted from the Peripheral Canal and Kellogg projects. If these projects are constructed, the only major direct diversion from the Delta for municipal and industrial water supply would be the planned North Bay Aqueduct. This diversion will be from Lindsey Slough in the north Delta. While the quality of water at this point will steadily deteriorate due to increasing salinity incursion in the future, this study has shown that there will be no additional deterioration in this area from salts discharged by the Drain. However, a detrimental effect is likely to occur from increased enrichment and resulting biological growth.

It is expected that non-recirculated industrial cooling water will continue to be diverted from Suisun Bay and the western Delta in the future. There will probably be some detrimental effects to this use resulting from increased biological growths because of higher nitrogen levels in the off-shore waters.

The timing for construction of the Kellogg and Peripheral Canal projects and for the discharge of Drain waters will have an effect on whether any damages occur to existing municipal and industrial water users in the western Delta due to the Master Drain. If the Drain discharge should start at the Antioch site before satisfactory arrangements have been made for suitable alternate water supplies to replace the off-shore supplies now used, some economic damage to these supplies could occur

AGRICULTURAL USES

Water Quality Requirements

When irrigation water is applied to agricultural land, some of it may run off as surface flow or be lost by direct surface evaporation, while the remainder infiltrates the soil. Of the infiltrated water, a part is used consumptively by the growing plants, a part is held by the soil for subsequent evapotranspiration, and the remaining surplus, if any, moves downward through the soil to the ground water table or laterally to a drainage channel or to a surface stream at a lower elevation. The water retained in the soil is known as the soil solution. It becomes more concentrated with dissolved salt as relatively pure water is utilized by plants or lost by upward capillary action and evaporation. The concentration of salts in the soil solution can only be reduced by dilution with fresh irrigation water or rain, and by downward movement of excess water.

Excessive accumulation of salts in the soil solution adversely affects plant growth. These effects involve: (a) direct physical effects of salts in preventing water uptake by plants (osmotic effects); (b) direct chemical effects upon metabolic reactions of plants (toxic effects); and (c) indirect effects through changes in soil structure, permeability, and aeration. Unless prevented by leaching, the slow filling of the soil with salts will result in highly concentrated soil solutions, and force the abandonment of an irrigated area. This has occurred in localized areas in the western United States and was probably the cause of failure of many ancient irrigation systems.

Absolute limits to the permissible concentrations of salts in irrigation water cannot be fixed for several reasons: (a) the soil solution is normally at least three to eight times as concentrated as the water that replenishes it; (b) there is no definite relationship between the composition of the irrigation water and that of the soil solution; (c) plants vary widely in their tolerance to total salinity and specific salts; (d) soil types, climatic conditions, such as rainfall, temperature and humidity, and irrigation practices may all influence the reactions of the crop to the salts; (e) interrelationships between and among constituents may be highly significant; and the effect of one ion may be modified by the presence of another.

Good drainage of the soil may be as important for plant growth as a low irrigation water salt content. Even when excellent waters are used, poorly drained land may go out of production, while highly saline waters can sometimes be successfully used on open well-drained soils.

Because of all the variables involved, water quality standards for irrigation use must be somewhat arbitrary and the limits cannot be rigidly set. The findings of many studies, particularly those of the University of California and the Regional Salinity Laboratories of the U. S. Department of Agriculture, have resulted in the classification of irrigation water into broad categories designated as: Class I, excellent to good or suitable under most conditions; Class II, good to injurious or harmful to some plants under certain conditions; and Class III, injurious to unsatisfactory or harmful to most plants under most conditions. These classes are occasionally further subdivided into such categories as: (1) excellent; (2) good; (3) permissible; (4) injurious; and (5) unsatisfactory. Detailed classifications of irrigation waters by various entities are summarized in Table 26. These classifications show the upper limit of salinity of Class I irrigation water ranges from 350 to 700 mg/l.

Available information indicates that Class I irrigation water for Delta soils will have an upper limit of salinity falling within a range of 300 to 500 mg/l total dissolved solids. Use of irrigation waters exceeding these limits on Delta soils will likely result in the accumulation of salt in the root zone and adversely effect crop growth or require the application of additional leaching water.

Existing Water Quality

With the exception of some localized areas, the present mean quality of water diverted from Delta channels for agricultural use during median water years is considered to be satisfactory.

Based upon mathematical model studies the mean annual quality of Delta agricultural water diversions (weighted according to diversion flow rates) is estimated to be 268 mg/l TDS under present conditions and median year outflow. Since other constituents do not exceed Class I criteria, present Delta agricultural diversions, on a mean annual basis, are considered as Class I irrigation waters. It should be understood that variations in quality with season and geographical location causes some agricultural diversions to be inferior to the weighted mean quality, e.g., in July the quality of 16.6 percent of the total agricultural diversions fall within the 500 to 1000 mg/l TDS quality class. However, the weighted mean salt concentration provides a satisfactory overall measure of quality for purposes of this analysis.

Even with the present relatively high quality of Delta waters for agricultural purposes, it is necessary to leach the peat soils of the Delta lowlands to remove the accumulation of salts in the root zone. Salt accumulation in the root zone in this case is due to the generally high water table and to the sub-surface irrigation practice used.

On the Delta upland mineral soils, irrigation water is normally applied to the surface of the soil by gravity flow. The water applied to the surface infiltrates downward into the soil. With Class I irrigation water, normal irrigation practice plus rainfall provides sufficient excess water to accomplish the required leaching and thus avoids excessive accumulation of salts in the root zone.

TABLE 26

DETAILED CLASSIFICATION OF IRRIGATION WATERS

Reference	EC X 10^6 at 25°C	Total Salts mg/l	Percent Sodium	Boron[1] mg/l	Chlorides Meq/liter	Sulfates Meq/liter
CLASS I						
1	< 500	<350	<30	0.5-1.5	<5.5	< 5.5
2	< 500	<350	<30	0.5-1.5	---	---
3	< 750	<525	<40	0.67-1.33	<7.0	< 7.0
4	<1000	<700	<60	0.5[2]	---	---
5	<1000	<700	<60	0.5[2]	<5.0	<10.0
CLASS II						
1	500-2500	350-1750	30-70	0.5-3.35	5.5-16.0	5.5-16.0
2	500-2500	350-1750	30-70	0.5-3.35	---	---
3	750-3000	525-2100	40-80	0.67-3.75	7-20	7-20
4	1000-3000	700-2000	60-75	0.5-2.0 [2]	---	---
5	1000-3000	700-2100	60-75	0.5-2.0 [2]	5-10	10-20
CLASS III						
1	>2500	>1750	>70	>1.12- >3.35	>16	>16
2	>2500	>1750	>70	>1.12- >3.35	--	--
3	>3000	>2100	>80	>1.25- >3.75	>20	>20
4	>3000	>2000	>75	>2.0 [2]	--	--
5	>3000	>2100	>75	>2.0 [2]	>10	>20

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[1] Lowest Value of range applies to sensitive plants, highest to tolerant plants.

[2] Semi-tolerant plants only.

Source of information; references [39, 40, 41, 42, 43].

Future Water Quality and Associated Economic Effects

Using total dissolved solids (TDS) as the quality indicator for agricultural water use, mathematical model analyses were made to determine future water quality levels. Under 1990 conditions of planned development and depletion of Delta outflow to 1500 cfs, the weighted annual mean TDS of Delta agricultural diversions would be 619 mg/l, a 2.3 fold increase in salt concentration over the present. Approximately 13 percent of the total agricultural diversions would exceed 1500 mg/l and 49 percent would exceed 500 mg/l TDS. Under these conditions, the impact on Delta agriculture would be extremely adverse. Without a substitute overland supply of good quality water, forced abandonment of about 65,000 acres in the western Delta would likely occur representing a gross loss in crop production of about $19,000,000 annually. Decreased crop yields, forced switching to more salt tolerant crops, and sharply increasing farm irrigation and leaching costs would occur on about 182,000 acres. Leaching costs would likely increase on an additional 253,000 acres. Preliminary estimates of net detriments to Delta agriculture and to the local economy which would occur are quite conservatively estimated to range between 10 and 20 million dollars annually.

Since detriments of this magnitude would be intolerable and since the "Delta water quality criteria" currently being negotiated by the construction agencies and representatives of Delta agriculture would be grossly exceeded at 1500 cfs outflow, additional water quality predictions were made to determine the impact of maintaining Delta outflow during the summer months at near the present level.

The economic impact on agriculture of discharging the Drain at Antioch is a function of Delta outflow and concentration of salinity of the inflows. Under 1990 conditions and with an outflow of approximately 2800 cfs, the impact of the Drain on agricultural diversions would be zero. With outflows below 2800 cfs, the impact would be beneficial. This relationship is graphically shown in Figure 30.

Under July 1990 conditions, and with a Delta outflow of 3000 cfs plus discharge of the Master Drain at Antioch, the weighted mean quality of agricultural diversions would be 358 mg/l TDS. While the "Delta water quality criteria" would be met at this outflow, it would result in a slight increase in leaching costs on Delta organic soils over that of the present. Presumably this quality of water would, however, be acceptable to Delta agricultural interests that will be a party to the contract being negotiated.

Under the same 1990 conditions of development, 3000 cfs Delta outflow, but without the Master Drain discharge to the Bay-Delta system, the weighted mean quality of agricultural diversions would be 346 mg/l TDS. The impact of the Drain would be slight, i.e., an increase of 12 mg/l TDS. This difference would increase to 100 mg/l TDS in 2020.

Monetary estimates of the detrimental impact on agriculture attributable to the Drain under the assumed conditions of 3000 cfs Delta outflow were estimated on the basis of the difference in leaching costs. The annual detriment in 1990 was computed to be $180,000. By the year 2020, this detriment would increase to $1,500,000 annually. The total present worth of the detriment over the 100 year evaluation period would be $30 million. This detriment could, of course, be further mitigated by increasing Delta outflow over the 3000 cfs base flow used in the analysis or by extending the Drain discharge point westward.

It should, however, be clearly understood that a significant proportion of the agricultural drainage effluent is the result of the proposed exportation of some 5,000,000 acre feet of water (1990) primarily for irrigation use in the San Joaquin Valley. Agricultural use of both the exported waters and local waters results in the concentration of salts in the agricultural drainage waters. A portion of the agricultural return flows will be collected by the Master Drain and returned to the Delta with discharge at Antioch. The proposed exportation of large quantities of water from the Delta for agricultural, municipal and industrial uses results in depletion of Delta outflow. Depletion of Delta outflow in combination with increased inflow of waste waters results in a significant deterioration of mineral water quality in Delta channels.

To determine the impact of discharging the San Joaquin Master Drain on the quality of the receiving waters, it was necessary to incorporate into the analysis the combined impact of the planned exportation of water and the resulting depletion of Delta outflows. However, the optimum Delta outflow which will minimize detrimental effects and maximize beneficial effects of increasing Delta water exports and increasing waste loads generated by use of the exported water will require additional study.

THE FISHERY

Water Quality Requirements

Maintenance of a healthy estuarine fishery requires protection of all life cycle phases and all habitats where fish live or through which they migrate. Spawning and nursery areas, such as the Delta and Suisun Bay, are particularly important. Certain general water quality criteria determine the suitability of these areas as an environment for supporting a desirable fishery. Dissolved salt concentrations, salt gradients and temperature are important in determining spawning times and areas; dissolved oxygen (DO) is important to survival of eggs, fry, young, and adult fishes. Depressed dissolved oxygen levels decrease growth rates, swimming speeds, forage ability, spawning success, and make aquatic animals more susceptible to toxins and disease. In this evaluation of the effects of the San Joaquin Master Drain, dissolved oxygen is considered to be the most critical of these basic water quality indicators.

The most important species of fish likely to be affected are the anadromous fishes, i.e., those which migrate from salt water to fresh water to spawn. The principal anadromous fishes found in the Bay-Delta system in order of their economic value are striped bass, king salmon, and American shad. Using available information concerning effects of sub-lethal DO concentration on growth and viability of fish populations [44, 45] it was possible to develop the curve shown in Figure 31 that relates DO to survival and well-being of anadromous fishes passing through the affected area. This relationship, then, provides the basic water quality objective, i.e., the dissolved oxygen level that results in no significant losses to the fishery.

Dissolved oxygen content of waters can be depressed when excessive quantities of decomposable organic wastes are discharged to the system. This should not be a problem in the Bay-Delta system except for isolated situations, since conventional treatment of sewage and industrial wastes is capable of removing these materials to reasonable levels. The Master Drain effluent will contain little of these materials, but will contain significant quantities of nitrogen which can indirectly cause depressed oxygen levels.

Nitrogen is the limiting plant nutrient in most of San Francisco Bay and the western Delta at the present time. Experiments conducted both in the laboratory and in the field have demonstrated that increased inorganic nitrogen stimulates growth of resident Bay-Delta planktonic algae [38]. These microscopic plants live suspended in the water, contain chlorophyll, and through photosynthesis, can produce oxygen when exposed to light while continuously consuming oxygen for normal respiratory requirements. Thus, they can be detected by the diurnal fluctuation of DO they produce in natural waters. As shown in Figure 32, this can lead to super-saturation of DO in shallow water systems and depressed DO in deep turbid waters.

A relationship between algal density as represented by their chlorophyll content and minimum daily summer DO concentrations has been developed for the western Delta and Suisun Bay. The basis for this relationship, shown graphically in Figure 33, is described in detail in an Appendix to this report. Having previously established a DO quality objective for these waters (Figure 31) it is possible, using Figure 33, to select the corresponding chlorophyll concentration that should not be exceeded so as to prevent any loss to the anadromous fishery. For the western Delta and Suisun Bay, these levels are 50 and 100 µg/l, respectively.

It is also possible to relate chlorophyll levels to nitrogen concentrations in the receiving waters. Experimental work and field observations in similar estuarine situations led to the development of the relationship shown in Figure 34 [38]. Ratios of 20 to 40 units of organic nitrogen per unit of chlorophyll encompass most of the field observations, while laboratory data show that algae in relatively pure cultures are best represented by a lower ratio (5:1). The presence in natural systems of detritus, bacteria, grazing animals, and soluble organics account for the higher ratios found in the field.

From Figure 34, it is evident that a mid-range value for total nitrogen between 1 and 3 mg/l would control chlorophyll levels to the desired level in the Delta and Suisun Bay and a value of 2 mg/l has been selected for use. Maintenance of this water quality objective, then, should adequately protect the important fishery resources of the system from damage due to enrichment-related dissolved oxygen depressions.

Existing Water Quality

As described in Chapter VII and shown graphically in Figure 24, there are a few localized areas of the Bay-Delta system where the nitrogen water quality objective is not met at the present time. In these areas chlorophyll levels have been observed to exceed 100 µg/l, significant dissolved oxygen depressions do occur, and available information indicates that fishery damages have resulted. In general, however, the Delta and Suisun Bay have total nitrogen concentrations between 0.7 and 1.6 mg/l and average summer chlorophyll concentrations range from 20 to 50 µg/l [22, 38, 46].

Future Water Quality

Predictions of future nitrogen concentrations as described in the previous chapter and shown in Figures 25 and 27 reveal that the water quality objective required to protect the anadromous fishery will be greatly exceeded throughout Suisun Bay and the Delta due to the discharge of treated municipal and industrial waste effluents, the Master Drain, tributary streams, and local agricultural drainage. In addition, it has been predicted that the suspended sediment concentrations will be less in the Delta-Bay system in the future which will allow greater light penetration and greater likelihood of increased algal densities. No significant changes in the water temperatures currently found in the Bay and Delta are expected.

These nitrogen predictions, when translated into algal densities using Figure 34, result in the estimates of future chlorophyll levels shown in Figure 35. This information when interpreted in terms of the associated dissolved oxygen levels, indicate that significant fishery losses would result if these conditions are allowed to prevail.

Economic Effects

The method for estimating the detrimental effect of the planned Drain discharge at Antioch is based on the presumption that water quality will be maintained in the future, approximately at the levels now existing which, in general, satisfies the desired quality objective. The incremental nitrogen concentrations due to the Drain (e.g., Figure 26 and 28) are thus superimposed on a base concentration equal to the present levels in the discharge area. The incremental detriment caused by this increase is the calculated effect of the Drain.

The incremental nitrogen concentrations due to the Drain may be connected to relative losses of resident fishes using the relationships described above. Then, by using this knowledge together with the seasonal distribution patterns of anadromous fishes, an estimate of the reduction in fish populations may be made.

The seasonal and spatial distribution of anadromous fishes was obtained from published information and is summarized in a qualitative manner in Table 27 [47, 48]. This information, expressed as the probability of an upstream or downstream migrant being in Suisun Bay or the western Delta between May and October, combined with the probability of loss of resident fishes at a given level of water quality (Figure 31) was applied to known existing fish populations to yield an estimate of the reduced population that would exist in the presence of the predicted water quality deterioration. The relative population reductions expected are shown in Figure 36 for the three anadromous species of major interest.

A decline in fishery population affects the demand and derived value for the fishery. The sports angler catches fewer fish, and as a result, enjoys his experience less and may not fish as frequently as he would if the fishery population was larger. These two consequences of a declining fishery lead to some variations in evaluating the economic consequence of this decline. The basic value of the sports fishery is calculated as the product of the demand (measured in angler days) and benefit (measured in dollars per angler day as a function of species). The value of an angler day was separated into two components, i.e., 1) the value of the outdoor recreational experience of fishing, and 2) the value of a fish caught in the recreational experience. The potential demand in future years is estimated from future population predictions, (demand for fishery) = (constant factor) (population), and modified by a consideration of the effects of decreased catches per angler [21]. These factors are incorporated in a fishery demand model. An economic valuation model is developed from the theory of the "rational consumer." It represents the individual fisherman's value for a day's fishing experience as a function of his day's catch; therefore, the decrease in his catch causes a reduction in the benefit (value) of that day's fishing. This decrease in value per day is a function of the total fishery population. The combination of the relative fishery population prediction with the demand and valuation models is accomplished in a fishery value detriment model where the fishery population is used to calculate the demand (in angler days) and value (per angler day). The product of the desired demand and the decrease in value due to the change in the fishery results in the prediction of the economic effect on the fishery which is depicted in Figure 37. The change in the value of the salmon fishery includes both the sports and commercial fishery. Detriments to the latter are calculated as the product of the net value per pound and the reduction in commercial catch. As shown by this figure, total anadromous fishery detriments would be from 4.4 to 9.1 million dollars in 1990 and from 8.0 to 12.4 million dollars in 2020.

TABLE 27

ANADROMOUS FISH - DISTRIBUTION PATTERN

FISHERY	AUTUMN	WINTER	SPRING	SUMMER
Striped Bass				
Adults	Bay & Delta	Bay & Delta	Spawn in Delta	Bay & Ocean
Young	Bay & Delta	Bay & Delta	Delta	Delta & Bay
King Salmon				
Adults	Spawn in rivers and die	- Immature	Adults In	Ocean ---
Young	Ocean	Eggs Maturing	Fingerlings Move Downstream	
American Shad				
Adults	Ocean	Ocean	Spawn in Rivers	Return to ocean or die
Young	Move toward ocean	Ocean	Fingerlings Move	to Delta and Bay

The complete chain of events that has been considered to relate increased nitrogen concentrations to economic effects on the fishery is summarized schematically in Figure 38. The development of each of the models shown in that diagram, together with a description of their interrelationships, is presented in the appendix to this report.

OTHER USES

Other water-related activities affected by the projected nutrient enrichment resulting from the San Joaquin Master Drain and other waste discharges include shoreline residential developments, boating and navigation, recreation and aesthetics, and wildlife propagation and sustenance. Some of the effects of nutrient enrichment on these uses can be described and quantitative estimates made of their economic costs.

Shoreline Residential Developments

There is an important trend in the present real estate market toward large scale residential development of shoreline areas. Typically, these developments are designed to capture some of the amenities associated with the building site including water views, backyard boat docking, fishing, swimming and water skiing. The market value of these developments (land and improvements) is in the hundreds of millions of dollars.

Water quality problems related to insects, turbidity, odor, and algal discolorations have occurred in some water-oriented real estate developments. Water quality maintenance costs are expected to increase. Costs incurred will be reflected in property values, and where problems are severe, property owners will suffer large economic losses. To illustrate the potential magnitude of these losses, we might find that the typical premium of $10,000 per lot in water-oriented areas could be reduced to a level of $5,000 through degradation of the water-oriented amenities that originally justified the higher premium. This would represent a loss of approximately $250 million (based on 50 square miles of developed Bay shoreline).

Boating and Navigation

Water quality affects boating and navigational uses principally in the marine regions of the Bay where various fouling organisms and marine borers thrive. Fouling organisms such as algal scums, barnacles, tunicates, and mussels attach themselves to boat hulls, wharves and channel buoys. Fouling organisms must be removed from boat hulls and marker buoys before protective paints are broken down or damages will result (i.e. corrosion, marine borers). Pleasure boats which are kept in Bay marinas generally undergo hull maintenance every 9-12 months. Boats in some enriched areas require more frequent hull maintenance (6-8 months). Fouling organisms may respond to nutrient enrichment directly (algal scums) or indirectly (barnacles). Barnacles and other fouling animals consume diatoms and other microscopic life in surrounding waters.

Projected marina berths and hull maintenance costs for pleasure boats are presented in Table 28 [20]. Hull maintenance projections are based on 100 percent berth occupancy, 20 foot average craft length, $3.00/lineal foot hull maintenance charges and one maintenance haul out per year [38].

TABLE 28

PROJECTED MARINA BERTHS AND HULL MAINTENANCE COSTS

	1965	1990	2020
Number of Berths	6,500	15,000	30,000
Hull Maintenance Costs	$392,000	$900,000	$1,800,000

Hull maintenance frequencies may increase to two haul outs per year for boats berthed in enriched saline areas, particularly where friction losses are important such as in sailboat racing. Improved antifouling paints, chemical control of growths and resistant hull materials will probably offset some of the expected increases in pleasure boat hull maintenance costs.

Recreation and Aesthetics

Recreational uses of the Bay-Delta system include water related activities such as swimming, water skiing, pleasure boating and fishing, and peripheral activities including sunbathing, hiking, hunting, and bird watching. Residential and commercial areas also derive value from their proximity to, or view of, the water and utilize the shore areas as a recreational site or for aesthetic appeal. The effect of possible future water quality changes in fishing, shoreline residential developments, and boating have been discussed in previous sections.

The remaining categories of recreation and aesthetic benefits that are derived from the Bay-Delta system provide a significant quantity of benefits to residents and visitors to the Bay-Delta area. About one-third of the total of the estimated economic benefits of recreation for the study area in years 1990 and 2020 are accounted for by these "other" categories: for Central San Francisco Bay, San Pablo Bay, Suisun Bay and Delta area, the estimated benefits are $20 million in 1990 and $37 million in 2020 for such activities as swimming, sightseeing, water skiing, picnicking, and nature walking [20].

An example of the effects of nitrogen enrichment is the problem of blue-green algae. In recent years, blue-green algal populations have surpassed nuisance levels in enriched dead-end sloughs of the Delta during the summer recreational season [49]. In the future, fresh water channels of the Delta may become noticeably discolored or support floating scums of blue-green algae at total nitrogen concentrations above 1.5 mg/l. The consequence of these algal growths will be less enjoyment of swimming and water skiing in the Delta area and a tendency to seek out other recreational areas at a place further away. In one case, the value of the recreation experience is decreased if the recreating is done in the Delta area. In the second case, the recreation may provide the same type of benefit, but the consumer has incurred higher costs to realize the recreational experience. Either case represents a loss in value, perhaps only 10 percent, but possibly as high as 50 percent if travel to another site is involved.

Based on this possible 10 to 50 percent decrease in value and the estimated values of $20 million and $40 million for these "other" recreation and aesthetic experiences, the possible economic value of the changes in water quality are 2 to 10 million dollars for 1990 and 4 to 20 million dollars for 2020.

Wildlife Propagation and Sustenance

Waterfowl, mammals and other game depend upon the marshes and waters for food and shelter. Wildlife resources may be reduced by water quality degradations resulting from over-enrichment (affecting fish and other aquatic food sources) or from salinity effects on marsh vegetation following reduction in Delta outflow [48].

Some of these changes in wildlife can be related to a monetary measure, such as a possible decrease in the hunting success caused by a reduction in waterfowl populations using the Bay-Delta area. Nature hikers also are affected, but the greatest impact will be felt by the protected forms of wildlife which have no monetary equivalent.

Costs Attributable to Drain

None of the economic detriments estimated above can be wholly attributed to a single waste discharge since many such discharges contribute to the nutrient enrichment problems foreseen. The magnitude of these problems have been estimated on the assumption that the level of total nitrogen in the Bay-Delta system will be maintained at the desired objective by treatment or diversion of tributary wastes. The incremental addition by the Drain discharge will then create the type of problems described above. These problems will not affect the entire study area and the total nitrogen content of affected waters will only be partially due to the Drain discharge. The economic costs estimated above have been adjusted, therefore, to reflect the portion that may be attributed to the Master Drain. This adjustment and a summary of the economic costs described above are shown in Table 29.

TABLE 29

PROBABLE ECONOMIC CONSEQUENCES OF NITROGEN ENRICHMENT
(Excluding Fishery)

Water Use	Nature of Effects Expected	Economic Magnitude of Effect	Attributable to Master Drain
Shoreline Residential Developments	Loss in amenities lowering property values	Potential decrease in property value may reach $250M[1] sometime between 1990 and 2020 (equivalent to $20M a year with an 8% capitalization rate)	25%
Pleasure boating	Increase in maintenance costs due to boring and fouling organisms	Potential increase in hull maintenance costs by 1990, about $.9M, by 2020, about $1.8M.	50%
Recreation and Aesthetic users other than shoreline residents, pleasure boating and other fishery	(1) Loss in enjoyment and amenities of being near, in or on the waters of Bay and Delta	(1) Time and travel costs expended for substitute experiences may be in these ranges - by 1990 $2-10M, by 2020, $4-20M.	50%
	(2) Change in environmental ecology of wildlife resulting in decline of populations of desirable species	(2) Effect on nature walking included in values above and a decline in the value of hunting experience less than $0.5M.	50%

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[1] M = million

X. ALTERNATE PLANS FOR DRAINAGE DISPOSAL

On the basis of findings previously described it has been concluded that the planned discharge of the Master Drain to the Delta at Antioch would cause significant damages to these receiving waters. It was also shown that extension of the Drain westward to a discharge point in Suisun Bay would not greatly reduce these undesirable conditions. Other methods for the non-pollutional discharge of these waste waters are considered below. These alternate plans may be grouped according to 1) treatment, 2) diversion, and 3) evaporation. Each of these and combinations of them should be considered in determining the most feasible disposal scheme that effectively prevents the pollution of receiving waters.

TREATMENT

The pollutants of major concern in the Drain waters are various salts, nutrients, particularly nitrate-nitrogen, and pesticides. Treatment for removal of such materials requires methods beyond those conventionally used to remove the readily degradable organics found in sewage. These advanced methods fall into two classes: 1) demineralization processes, and 2) special nutrient removal processes.

Demineralization Processes

Demineralization processes provide for the separation of salts from brackish or saline waters to permit their re-use for practically any purpose. Of the many processes studied by the FWPCA Advanced Waste Treatment Program [50, 51] and the Office of Saline Water [52], four appear to be most feasible: 1) electrodialysis, 2) ion exchange, 3) distillation, and 4) reverse osmosis. A comparison of costs for these and other processes is presented in Table 30. Each of these processes can produce a water having a very low content of salts and other pollutants. In each case, however, a concentrated waste residue remains which still presents a disposal problem. The salts removed are concentrated in a waste flow approximating 10 to 30 percent of the feed water flow rate.

The most promising of these processes for the treatment of tile drain waters are electrodialysis and reverse osmosis. These will be evaluated for specific application to San Joaquin tile drain waters in a joint FWPCA-Office of Saline Water pilot plant beginning early in 1967. However, because of their high operating costs and the need to dispose of concentrated brines it does not appear that these demineralization processes will offer a solution to disposal of San Joaquin Master Drain waters in the immediate future. If, through process developments, operating costs can be lowered significantly, these processes may find application as a long range solution.

Special Nutrient Removal Processes

As discussed elsewhere, nitrate-nitrogen is the constituent of Drain water which is most likely to cause a problem if discharged to the Delta-Bay system. Two biological treatment methods have been proposed for its removal: 1) algae production and harvesting [54], and 2) anaerobic denitrification [55]. Estimated costs for these two processes are presented in Table 30. The California Department of Water Resources is planning prepilot plant studies to confirm their feasibility and costs.

Algae Production and Harvesting. This process involves routing the waste water into shallow ponds designed to promote maximum algae growth followed by a harvesting procedure to remove the algae from the waste stream. It is estimated that 50 to 90 percent of the nitrogen could be removed by this process depending on climatic conditions, pond design and harvesting method selected. Disadvantages appear to be large land area requirements and problems associated with the disposal of large quantities of harvested algae. This process could also be expected to remove traces of pesticides that may be present in the waste water, concentrating them in the harvested algae.

Anaerobic Denitrification. This process is estimated to be capable of removing up to 90 percent of the nitrogen from the Drain water. This process is particularly attractive because of its simplicity and low capital cost. An organic chemical, such as methanol, is added to the waste stream to provide a carbon source for bacteria. The waste is then routed through a deep reservoir with sufficient capacity to provide a 10 day (or possibly less) detention period prior to discharge. Enroute through the reservoir, the dissolved oxygen in the waste stream is depleted by bacterial degradation of the carbon source. Under such anaerobic conditions, common denitrifying bacteria reduce nitrate nitrogen to nitrogen gas which is lost to the atmosphere. There are no waste products requiring disposal and it is reported that no odor problems result. The only disadvantage seems to be a very slight increase in BOD and turbidity in the effluent stream which must be reaerated before discharge. It is likely that the bacterial solids produced would also adsorb some fraction of any pesticides in the waste waters.

Other Processes. It is possible that other nitrate removal processes could be developed for application to the treatment of tile drain waters. One such method is an ion exchange process using a resin which is selective for the nitrate ion. This type of resin exists but its applicability to drain waters and the costs of treatment are not known. Chemical denitrification may also offer some possibilities. Finally, biological denitrification may possibly be performed more effectively on columns of soil, rock or other substrates than in ponds.

TABLE 30

COMPARISON OF TREATMENT COSTS
SAN JOAQUIN MASTER DRAI WATER

Process	Total Costs[1] ($ per Acre Foot)	Treated Water Uses	Removal Achieved
Demineralization[2]			
Electrodialysis	97	Agriculture	TDS to 700 mg/l
Ion Exchange	>140	M & I and Agriculture	TDS to < 100 mg/l
Distillation	118	M & I and Agriculture	TDS to < 100 mg/l
Reverse Osmosis	74	M & I and Agriculture	TDS to < 100 mg/l
Nitrogen Removal[3]			
Algae Stripping	5½ to 10	Possible Salinity Incursion Control[5]	50-90% Nitrogen
Denitrification	8½		90 +% Nitrogen
Conventional Treatment[4]			
Primary	12		30% Nitrogen[6] 30% BOD
Primary plus Secondary	20		40% Nitrogen[6] 85% BOD

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[1] Present worth @ 3 1/8% for 50 year plant life. Includes capital, operation, maintenance and power costs f r 100 mgd plant capacity.

[2] Does not include land, storage facilitie , or pretreatment costs. Cost estimates are subject to change pending echnological advances, nuclear power availability and field evaluation f large plants.

[3] Includes land, storage and pretreatment osts.

[4] Present-day practice for treatment of mu icipal wastes shown for comparison purposes. Not suitable for t eatment of drain waters.

[5] For comparison purposes, estimated cost f providing Delta outflow from upstream storage is $8.25 to $10.70 per cre-foot [53].

[6] Assuming digester effluents not recircul ted.

Each of these and other possible treatment methods, as well as those mentioned above whose approximate costs are known, are currently being evaluated by a joint State-Federal task group. Participating agencies include the FWPCA, Bureau of Reclamation, Office of Saline Water and the California Department of Water Resources. These studies are designed to provide positive conclusions regarding treatment possibilities prior to the time that a Master Drain discharge will be necessary.

DIVERSION

Regardless of whether or not the Drain waters are treated, it will be necessary to move vast quantities of salt and other waste residues to an ultimate disposal site. A logical site for ultimate disposal of salts is the Pacific Ocean, and both the California Department of Water Resources and the U. S. Bureau of Reclamation have estimated the costs of ocean disposal for untreated Drain waters. Several routes from the San Joaquin Valley to the ocean have been studied. The most direct and least expensive route found to date is to a marine canyon off Monterey via Pacheco Pass and a route paralleling the Pajaro River. This route and several other alternative routes are shown in Figure 4.

Total costs for the routes shown in Figure 4 have been estimated by the California Department of Water Resources [33] and the U. S. Bureau of Reclamation [56] and are summarized in Table 31. Considerable reduction in total costs might be realized if the volume of waste were reduced by concentration in evaporation ponds prior to transportation. This would be particularly true of routes involving large power requirements such as the Pacheco Pass route where 26 to 30 percent of the total present worth is for power. Optimizing the cost of such facilities, however, is beyond the scope of this study.

A comparison of unit costs for transportation of wastes was derived from the total costs and is presented in Table 32. The costs for transporting wastes along the San Joaquin Valley floor in a lined canal is relatively inexpensive due to lower land costs and power requirements. By comparison, the transportation of wastes toward the ocean is expensive regardless of the route selected. The high unit costs in Contra Costa County are mainly due to high land values and increased construction costs but also include substantial power costs. The most direct route to the ocean via Pacheco Pass is approximately one-half the unit cost of transporting wastes through Contra Costa County, in spite of the higher power costs involved. This is an important consideration, particularly if a master plan of waste disposal for the Bay-Delta area should call for ultimate discharge to the ocean. It is possible, however, that the joint sharing of costs for construction of a larger drain facility through the San Francisco Bay region to accommodate municipal, industrial, and agricultural wastes could result in an overall cost reduction for handling the total waste disposal problem. It is expected that this possibility will be explored

TABLE 31

TOTAL COSTS OF DIVERSION PLANS
(In Millions of Dollars)

Discharge Point	Costs[1/]	
	USBR-400 cfs Terminal Capacity	DWR-900 cfs Terminal Capacity
Antioch	41 - 52[2/]	105[3/]
Monterey Canyon	110	235
Middle Point (Suisun Bay)	62	155[3/]
Martinez (Carquinez Strait)	-	183[3/]
Rodeo (San Pablo Bay)	-	234[3/]

[1/] Present worth @ 4% interest for 100 year project life. Includes capital, operation, maintenance and power costs.

[2/] Higher figure is DWR estimate and includes provisions for future expansion to 900 cfs terminal capacity.

[3/] Based on staged construction. First stage 400 cfs, second stage 900 cfs terminal capacity.

TABLE 32

DIVERSION UNIT COST COMPARISONS
SAN JOAQUIN MASTER DRAIN

Drain Location	Estimated Cost[1] ($ Per CFS-Mile)	Ratio[2]
San Joaquin Valley Floor (Kern County to City of Antioch)		
400 cfs Terminal Capacity	850	1.0:1
900 cfs Terminal Capacity	720	1.0:1
Contra Costa County (City of Antioch to City of Rodeo)		
400 cfs Terminal Capacity	4100	4.8:1
900 cfs Terminal Capacity	4000	5.6:1
1500 cfs Terminal Capacity	3900	5.4:1
San Joaquin Valley to Ocean (Dos Palos to Monterey Canyon via Pacheco Pass)		
400 cfs Terminal Capacity	2500	2.9:1
900 cfs Terminal Capacity	1750	2.4:1

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[1] Based on Present Worth of Capital Investment, Operation, Maintenance, and Power Costs (100 yr. @ 4%).

[2] 400 cfs values compared with 400 cfs Valley Floor Value.
900 and 1500 cfs values compared with 900 cfs Valley Floor Value.

by the California Water Quality Control Board's Bay-Delta Comprehensive Water Pollution Control Program studies. These were initiated late in 1966 and are scheduled for completion in 1969.

EVAPORATION

Evaporation rates in the San Joaquin Valley are high as a result of long, hot summers, mild winters and frequent strong winds. Estimated net evaporation is 50 inches per year from pond surfaces having a salinity greater than 50,000 ppm. Evaporation of the liquid portion of waste waters is attractive since it makes partial disposal possible near the area of waste origin. It is also attractive for use in conjunction with other disposal schemes to reduce the required carrying capacity of waste drains. Land requirements for total evaporation have been estimated by the California Department of Water Resources. Approximately 70,000 acres would be required to handle the total drainage from the Tulare Lake Basin (about 300,000 acre feet per year) and an additional 37,000 acres for drainage from the San Luis service area and areas north to about the northern Merced County line (about 160,000 acre feet per year). Disposal by total evaporation was estimated to cost from 1.5 to 3.3 times the cost of a drain (900 cfs terminal capacity) to Antioch depending on pond location and associated pumping costs. Stratigraphic surveys and infiltration tests have shown a number of potential evaporation pond sites where percolation of pond waters would not be a serious problem. Disadvantages include birdlife nuisance to surrounding agricultural areas and controls to prevent insect problems.

OTHER PLANS

In addition to the above, several other plans have been proposed for disposal of Drain waters or minimization of damage due to their discharge. These are described below.

Modification of Receiving Waters

Treatment of Municipal and Industrial Wastes. This plan would reduce the nitrogen load from municipal and industrial sources in the Delta - Suisun Bay area to provide greater capacity for assimilation of nitrogen from agricultural drainage. Present day technology indicates that treatment for nitrogen removal is feasible but costs are high. Conventional secondary treatment of municipal and industrial wastes can remove about 40 percent of the nitrogen provided digester effluents are withheld from receiving waters. Comparative costs for such treatment are presented in Table 30 . Greater removals will require additional treatment by other techniques such as those described above for treatment of agricultural wastes. The algal production and harvesting process requires significant land areas which are rapidly increasing in cost and decreasing in availability in the Bay area. Preliminary data for the denitrification process indicates that detention times can be reduced to less than 24 hours, perhaps 1 or 2 hours. However, the problem of converting the large quantities of the organic nitrogen normally found in sewage to nitrate-nitrogen, which is the necessary form for denitrification, is difficult to control and will require additional research and development to perfect. At the present time, denitrification of the Drain waters appears to be considerably more feasible than similar treatment of municipal and industrial wastes to remove nitrogen. In any case, however, a significant reduction in the amount of nutrient materials discharged by Bay area municipalities and industries will be required irrespective of the disposition of Drain wastes if appropriate water quality objectives are to be realized in the San Francisco Bay tidal system.

Diversion of Municipal and Industrial Wastes. An alternate to treatment for nitrogen removal is diversion of municipal and industrial wastes to other locations. Diversion to the sea is possible but costly as discussed earlier and opportunities for re-use are lost. Transportation of treated Bay area municipal and industrial wastes toward the San Joaquin Valley or elsewhere for re-use by agriculture is attractive since the dissolved solids content of Bay area wastes is relatively low (500 to 1000 mg/l) and the nutrient content high. The feasibility of such a plan is expected to be considered by the State Water Quality Control Board studies mentioned previously.

Augmentation of Delta Outflow. Flow augmentation through controlled releases from upstream reservoirs is a well recognized method for obtaining water quality improvement in streams by providing dilution and transport of waste waters during periods when stream flow is normally low. Flow augmentation in estuaries, however, is not as widely practiced because of the relatively larger flow requirements necessary to accomplish the same level of improvement as in streams. Augmentation of flow through estuaries for quality control is usually feasible only near the head of tidal influence as, for example, in the Delta. Flow requirements rapidly become quite large as the quality control point is moved toward the mouth of the estuary. The Bay-Delta problem is further complicated by plans for diversion of winter flows which normally provide a significant degree of "flushing" of accumulated pollutants to the ocean each year, (see Figure 8). Delta outflows will be controlled at minimum levels the year around for a number of years in succession during dry periods. Thus, flow requirements for water quality control must be determined for the entire year rather than some portion of the year. Costs for providing additional outflow through construction of upstream storage is estimated to range from about 8.25 to 10.70 dollars per acre foot [53].

Sub-Surface Injection

The possibility of disposal of Drain waters by injection into certain sub-surface aquifers of the San Joaquin Valley has been explored to a limited extent. The most promising scheme is that being considered by the Petroleum Research Office of the Bureau of Mines, U. S. Department of the Interior and the oil industry involving the injection of waste waters into oil-bearing aquifers to improve oil production in southern San Joaquin Valley. A research program is currently underway by the Petroleum Research Office with cooperation from Standard Oil of California, Shell Oil and the California Department of Water Resources to determine the degree of pretreatment required and associated costs. The study, which began in July 1966, will be completed in approximately two years. This scheme is of particular interest to the oil industry because of the possibility of acquiring large quantities of inexpensive water for injection purposes as contrasted with the cost of importing large quantities of sea water from the ocean which is also being considered. It has been estimated that by 1980 the oil industry in the Tulare Lake Basin could use 15,000 acre feet per year for secondary recovery of oil and that this need would continue for 40 years. Thus, the capabilities of this disposal method are limited both by capacity and duration.

INTERIM PLANS

Evaporation ponds as an interim measure for waste disposal for a period of 5 to 10 years appear entirely practical from an engineering and economic viewpoint. Much of the land could be reclaimed after the interim period for use as wildlife habitat, reregulatory storage, or for agricultural purposes. The U. S. Bureau of Reclamation, in its 1964 study of alternate solutions for San Luis drainage disposal [56], found that evaporation plans were less expensive than any dilution plan considered for handling drainage waters for a five year interim period. Table 33 presents a summary of the dollar savings which would result by deferring construction of the San Luis Drain or a portion thereof for five years and adopting one of the Bureau's interim plans. It is likely that similar savings would result from an analysis of interim plans for the larger initial drainage quantities predicted for the joint State-Federal San Joaquin Master Drain. As a part of this facility, an initial storage capacity of 56,000 acre feet is planned which will have an estimated surface area of 9200 acres. This storage and evaporation capacity could be used on an interim basis for several years before any discharge would occur. An increase in surface area could extend this time even longer with little change in overall costs provided construction of the northerly portion of the Drain is deferred.

While an interim plan would not provide for ultimate solution of the drainage problem, it could "buy" the time necessary to develop treatment methods or a comprehensive disposal plan for the entire Central Valley - San Francisco Bay complex. A combined disposal plan may be preferable

TABLE 33

COMPARISON OF ALTERNATE DISPOSAL SCHEMES TO HANDLE SAN LUIS DRAIN WASTES FOR INITIAL FIVE YEAR PERIOD
(Millions of Dollars)

Plan[1]	Present Worth[2]	Net Cost Saving By Deferment of Drain Construction[3]
Dilution Plans		
Plan 1A	6.21	- 0.13
Plan 1B	5.14	0.94
Plan 4A	3.14	0.19
Plan 4B	3.14	0.72
Evaporation Plans		
Plan 2	2.84	3.24
Plan 3	2.90	3.18

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[1] Plan designations are those of the Bureau of Reclamation. The dilution plans include various combinations of storage, dilution, and discharge to the San Joaquin River. The evaporation plans include centralized and localized ponding.

[2] Includes capital costs, operation, maintenance, power, and salvage values.

[3] Savings determined by the difference between present worth of interim plan and present worth of deferred San Luis Drain construction or appropriate portion thereof for 5 years.

to a single purpose agricultural drain plan and may be justified considering the projected population, industrial, and agricultural growth of these areas. The development of such a plan is a subject of considerable interest to the FWPCA and the U. S. Army Corps of Engineers in addition to the State Water Quality Control Board, as noted above.

COMPARISON OF DISPOSAL PLANS

The disposal of agricultural waste waters will directly benefit agricultural interests in the San Joaquin Valley by increasing the crop yields, income and land values and by protecting water supplies and agricultural soils. The California Department of Water Resources estimates that primary agricultural benefits to the Valley would exceed $471 million (present worth 1970). In addition, the estimated benefit created by decreasing the cost of public services such as maintenance and construction of County roads and mosquito abatement would exceed $40 million (present worth 1970). Recreation, fish, and wildlife benefits have not yet been completely evaluated.

The various alternative plans for disposal of the agricultural waste waters from the San Joaquin Valley have been studied to determine the most satisfactory method of minimizing economic and social costs. Several plans and options were studied. Each has its individual merits, including intangible values not easily expressed in monetary terms. The plans subjected to detailed analysis were narrowed to a reasonable number which represent a realistic range of costs and water quality effects. The selection of plans that could be compared on a common basis was complicated by the fact that they usually accomplished varying degrees of water quality and offered protection over different time periods. For example, the plan for discharge to the ocean which provides long-range protection and less uncertainty about future water quality cannot properly be compared with an interim plan which offers short-range protection and greater uncertainty about the future.

Recognizing these limitations, an analysis was made to compare the total economic and social costs of the three primary plans. The results of this comparison are presented in Table 34 . The other plans and options studied are not presented because either the costs or detriments were excessive. For example, costs for ocean disposal through 3 alternative alignments exceeded the cost of the Monterey Canyon route by more than 2 to 1. Detriments associated with alternative San Francisco Bay discharge points were only reduced slightly while transportation costs increased sharply. Costs of desalting the agricultural wastes so the waters could be reused are excessively high. Evaporation within the Valley, as a permanent solution, was rejected because of costs, detriments and opposition of Valley interests.

Combined ocean disposal of agricultural, municipal and industrial wastes generated in the San Francisco Bay-Delta area and the San Joaquin Valley was not considered because estimating the costs and benefits of such a comprehensive plan was beyond the scope of this study.

Transporting the salts out of the basin is considered to be the most satisfactory method of agricultural waste water disposal. Of the three such plans studied (Table 34), nitrogen removal and discharge to the Delta at Antioch or ocean disposal via the Monterey Canyon alignment are by far the most desirable from a pollution control standpoint.

TABLE 34

ECONOMIC AND SOCIAL COSTS[1] OF PRIMARY DISPOSAL PLANS
(In Millions of Dollars)

Alternatives	Transportation Costs	Treatment Costs	Detrimental Costs[2]	Total Costs	Drainage Benefits[3]
San Francisco Bay					
Antioch	105	-	367[4]	472	511
Antioch - Treated	105	98	28[5]	231	511
Ocean					
Monterey Bay	235	-	-	235	511

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[1] Total present worth 1970, 100 year project life.
[2] Accruing to San Francisco Bay-Delta water uses.
[3] Accruing to San Joaquin Valley agricultural and other interests.
[4] Midpoint of estimates which range from 253 to 481 million.
[5] Midpoint of estimates which range from 16 to 40 million.

Since the estimated total economic and social costs of these two alternatives as shown in Table 34 are approximately equal, it would be desirable to re-examine these estimates in detail. Proposed nitrogen removal processes have not yet been field tested and the cost of ocean disposal is considered to be a preliminary estimate. Further refinement of the costs of these two alternatives using the best available information could significantly affect a decision between them.

RECOMMENDED PLAN

On the basis of the studies described here it has been concluded that either disposal to the Delta after a high degree of treatment for nitrogen removal (at least 90 percent reduction) or disposal to the ocean without treatment would be acceptable alternatives that could satisfactorily meet appropriate water quality objectives. If ocean disposal is seriously considered, the technology is available to provide a proper design for the discharge and dispersion of waste materials in a manner that would minimize any localized adverse effects. The long term effects are more difficult to predict; however, there is as much, or more, reason to believe they would be advantageous as there is to believe they would be detrimental.

Since much developmental work with treatment methods remains to be carried out it would be useful to adopt an interim evaporation plan in order to make available the time necessary for this work.

At some date in the near future, viz. 1970, a more informed decision could be made concerning the relative economics of these two alternatives. Employment of an interim plan would provide this time plus an additional few years to implement the alternative selected.

XI. BIBLIOGRAPHY

1. U. S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION, REGION 2. 1966. Hydrologic Data for Central Pacific Basins Comprehensive Water Pollution Control Project.

2. CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES. 1962. Salinity Incursion and Water Resources. Delta Water Facilities. Bulletin No. 76, Appendix A.

3. ______________. 1966. Implementation of the California Water Plan. Bulletin No. 160-66.

4. ______________. 1957. Report of Sacramento - San Joaquin Water Supervision for 1955. Bulletin No. 23-55.

5. ______________. 1956. Investigation of the Sacramento - San Joaquin Delta. Quantity and Quality of Waters Applied to and Drained from the Delta Lowlands. Report No. 4.

6. U. S. DEPARTMENT OF AGRICULTURE, AGRICULTURAL RESEARCH SERVICE. 1959. Estimated Evaporation and Evapotranspiration Losses Under Various Proposed Barrier Plans of the San Francisco Bay System, California. Prepared for U. S. Army Engineer District, San Francisco, California.

7. CALIFORNIA STATE DEPARTMENT OF PUBLIC WORKS. 1931. Variation and Control of Salinity in Sacramento - San Joaquin Delta and Upper San Francisco Bay. Bulletin No. 27.

8. U. S. HOUSE OF REPRESENTATIVES, 80TH CONGRESS, FIRST SESSION. 1948. House Document No. 146.

9. U. S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION. 1951. Supplement to Its Application for Water Right Permit for the Central Valley Project. Cited in California State Department of Water Resources. 1957. Salinity Control Barrier Investigation. Bulletin No. 60.

10. CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES. 1960. Feather River and Delta Diversion Projects. Economic Demand for Imported Water. Bulletin No. 78, Appendix D.

11. U. S. DEPARTMENT OF COMMERCE, OFFICE OF AREA DEVELOPMENT, BUSINESS AND DEFENSE SERVICES ADMINISTRATION. 1959. Future Development of the San Francisco Bay Area 1960-2020.

12. STANFORD RESEARCH INSTITUTE. 1960. The California Economy 1947-1980.

13. U. S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS. 1965. Population Estimates. Series P-25.

14. CALIFORNIA STATE DEPARTMENT OF FINANCE. 1964. California Population.

15. CALIFORNIA STATE WATER QUALITY CONTROL BOARD, SAN FRANCISCO BAY REGION. 1966. Resolution Adopting a Policy Relative to the Protection of Public Health and Concerning the Beneficial Water Uses to be Protected in Tidal Waters Inland from the Golden Gate and Within the San Francisco Bay Region.

16. _______________. 1965. Beneficial Water Uses to be Protected and Receiving Water Conditions Needed to Protect Said Uses in the Tidal Waters Inland from the Golden Gate and Within the San Francisco Bay Region.

17. U. S. DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION, REGION 2. 1966. Peripheral Canal Unit, Central Valley Project, California.

18. _______________. 1963. Kellogg Unit, Central Valley Project, California.

19. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE, REGION IX. 1964. Water Quality Control Study, Peripheral Canal, Sacramento-San Joaquin Delta, California.

20. STANFORD RESEARCH INSTITUTE. 1966. Recreation and Fishery Values in the San Francisco Bay and Delta. Prepared for the Federal Water Pollution Control Administration, Southwest Region.

21. SKINNER, JOHN E. 1966. Estimates of the Use and Harvest of Fish and Wildlife Dependent on San Francisco Bay and Delta. California State Department of Fish and Game, Sacramento, California.

22. UNIVERSITY OF CALIFORNIA, SANITARY ENGINEERING RESEARCH LABORATORY. 1960-1965. A Comprehensive Study of San Francisco Bay. Annual Reports.

23. CALIFORNIA STATE WATER QUALITY CONTROL BOARD, SAN FRANCISCO BAY AND CENTRAL VALLEY REGIONS. 1960-1965. Published and Unpublished Data on Waste Discharges.

24. CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES. 1958 and 1963. Reclamation of Water from Sewage and Industrial Wastes in California. Bulletins No. 68 and 68-62.

25. CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES. 1966. Quality and Use of Waste Water, 1962-1966.

26. BABBITT, H. E. AND E. R. BAUMANN. 1958. Sewerage and Sewage Treatment. John Wiley and Sons, Inc., New York.

27. METCALF, LEONARD AND HARRISON P. EDDY. 1935. American Sewerage Practice. Volume III. Disposal of Sewage. McGraw-Hill Book Co., New York.

28. JOHNSON, W. K. 1958. Nutrient Removal by Convencional Treatment Processes. Proceedings of the Thirteenth Industrial Waste Conference, Purdue University.

29. BARTH, E. F., M. MULBARGER, B. V. SALOTTO, AND M. B. ETTINGER. 1966. Removal of Nitrogen by Municipal Wastewater Treatment Plants. Journal Water Pollution Control Federation, 38(7).

30. MULBARGER, M. C. Unpublished. Phosphorus Removal in Conventional Sewage Treatment. U. S. Department of Health, Education and Welfare, Public Health Service.

31. U. S. DEPARTMENT OF THE INTERIOR, FEDERAL WATER POLLUTION CONTROL ADMINISTRATION. In Preparation. Phosphate Removal by Activated Sludge. FWPCA Research Report, Robert S. Kerr Water Research Center, Ada, Oklahoma.

32. CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES. Unpublished. Delta and Suisun Bay Pollution Investigation.

33. ______________. 1965. San Joaquin Valley Drainage Investigation, Preliminary Edition. Bulletin No. 127.

34. STATE OF CALIFORNIA, THE RESOURCES AGENCY. 1966. Communication between the Resources Agency of California and the Federal Water Pollution Control Administration, Southwest Region.

35. WATER RESOURCES ENGINEERS, INC. 1965. A Water Quality Model of the Sacramento-San Joaquin Delta. Prepared for the Federal Water Pollution Control Administration, Southwest Region.

36. ______________. 1966. A Hydraulic Water Quality Model of Suisun and San Pablo Bays. Prepared for the Federal Water Pollution Control Administration, Southwest Region.

37. KRONE, R. B. 1966. Predicted Suspended Sediment Inflows to the San Francisco Bay System. Prepared for the Federal Water Pollution Control Administration, Southwest Region.

38. U. S. DEPARTMENT OF THE INTERIOR, FEDERAL WATER POLLUTION CONTROL ADMINISTRATION, SOUTHWEST REGION. In Preparation. Effects of the San Joaquin Master Drain on Water Quality of the San Francisco Bay and Delta. Appendix--Nutrients and Fisheries.

39. SCOFIELD, C. S. 1935. The Salinity of Irrigation Water. Smithsonian Report No. 275.

40. WILCOX, L. V. 1948. Agricultural Uses of Reclaimed Sewage Effluent. Sewage Works Journal, 20.

41. STONE, R. V., H. B. GOTAAS, AND V. W. BACON. 1952. Economic and Technical Status of Water Reclamation from Sewage and Industrial Wastes. Journal American Water Works Association, 44.

42. THORNE, D. W. AND H. B. PETERSON. 1949. Irrigated Soils, Their Fertility and Management. P. Blakiston's Son and Co., New York.

43. CALIFORNIA STATE WATER RESOURCES BOARD. 1951. Water Resources of California. Bulletin No. 1.

44. DOUDOROFF, PETER AND C. E. WARREN. 1962. Dissolved Oxygen Requirements of Fishes. In Biological Problems in Water Pollution. Transactions of the Third Seminar. U. S. Department of Health, Education, and Welfare, Public Health Service.

45. GERMAN, EUGENE R. 1958. A Review of Some of the Literature Dealing with the Oxygen Requirements of Fresh Water Fishes. California Department of Fish and Game, Inland Fisheries Administrative Report No. 58-18.

46. BAIN, RICHARD C. AND JAMES C. MC CARTY. 1965. Nutrient Productivity Studies in San Francisco Bay. U. S. Department of Health, Education, and Welfare, Public Health Service, Region IX, Central Pacific Basins Water Pollution Control Project Technical Report No. 65-1.

47. CALIFORNIA STATE DEPARTMENT OF FISH AND GAME. 1966. Ecological Study of the Sacramento - San Joaquin Estuary. Part 1. Bulletin No. 133.

48. STATE OF CALIFORNIA, THE RESOURCES AGENCY. 1961-1966. Delta Fish and Wildlife Protection Study. Annual Reports 1-5.

49. CALIFORNIA STATE DEPARTMENT OF PUBLIC HEALTH, BUREAU OF SANITARY ENGINEERING. 1962. Stockton - Delta Area Water Quality and Water Use Survey.

50. U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE. 1965. Advanced Waste Treatment Research. Summary Report, January 1962 - June 1964. PHS Publication No. 999-WP-24.

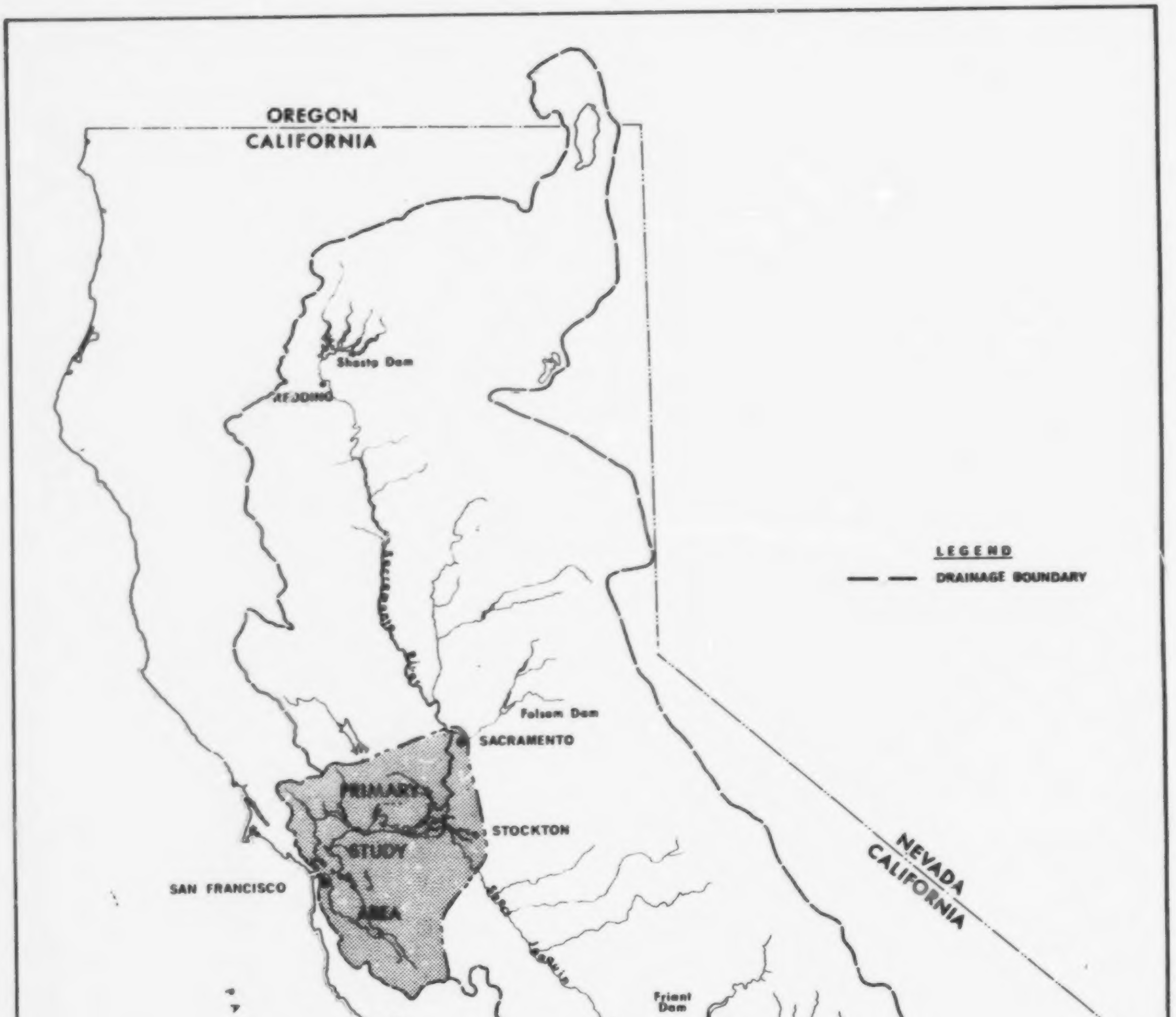
51. WALTON, GRAHAM. 1965. Feasibility and Cost of Treating and Recycling Agricultural Waste Waters Within Irrigated Area - San Joaquin Valley, California. U. S. Department of Health, Education, and Welfare, Public Health Service.

52. U. S. DEPARTMENT OF THE INTERIOR, OFFICE OF SALINE WATER. 1966. Saline Water Conversion Report for 1965.

53. INTERAGENCY DELTA COMMITTEE, TASK FORCE. 1964. Coordinated Plan for the Sacramento - San Joaquin Delta. Task Force Report.

54. OSWALD, W. J., D. G. CROSBY, AND C. G. GOLUEKE. 1964. Removal of Pesticides and Algal Growth Potential from San Joaquin Valley Drainage Waters (A Feasibility Study). Report to San Joaquin District, California State Department of Water Resources.

55. MC CARTY, P. L. 1966. Feasibility of the Denitrification Process for Removal of Nitrate Nitrogen from Agricultural Drainage Waters. Report to San Joaquin District, California State Department of Water Resources.

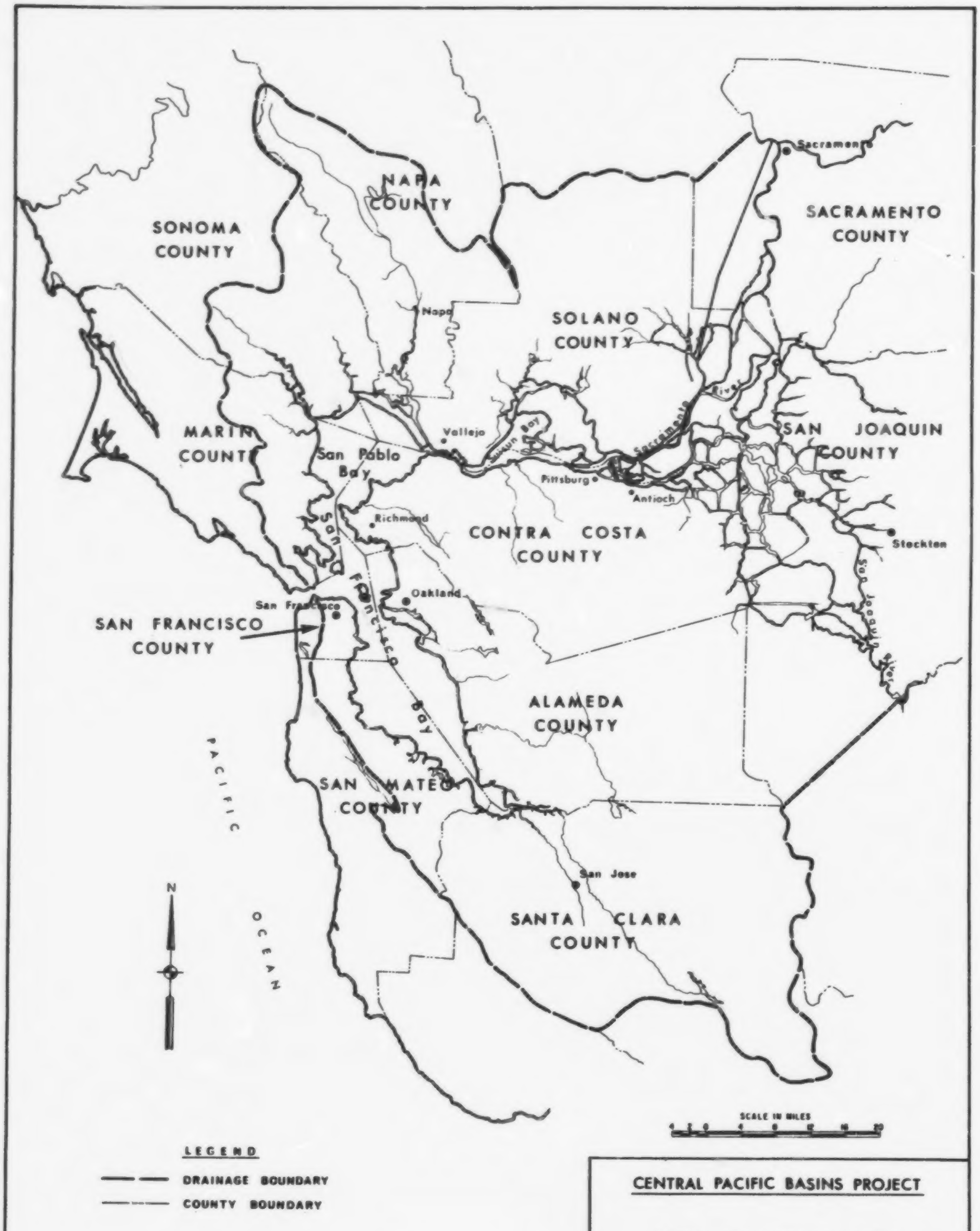

OREGON
CALIFORNIA
Shasta Dam
REDDING
Sacramento River
Folsom Dam
SACRAMENTO
PRIMARY
STUDY
AREA
STOCKTON
SAN FRANCISCO
San Joaquin River
Friant Dam
FRESNO
Tulare Lake Bed
BAKERSFIELD
NEVADA
CALIFORNIA
PACIFIC
OCEAN
LEGEND
DRAINAGE BOUNDARY
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

STUDY AREA

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
SAN FRANCISCO, CALIFORNIA

FIGURE 1


SONOMA COUNTY
NAPA COUNTY
Napa
SACRAMENTO COUNTY
Sacramento
SOLANO COUNTY
Sacramento River
MARIN COUNTY
San Pablo Bay
Vallejo
Suisun Bay
Pittsburg
Antioch
SAN JOAQUIN COUNTY
Stockton
San Joaquin River
Richmond
CONTRA COSTA COUNTY
Oakland
San Francisco
SAN FRANCISCO COUNTY
San Francisco Bay
ALAMEDA COUNTY
SAN MATEO COUNTY
PACIFIC OCEAN
San Jose
SANTA CLARA COUNTY
N
SCALE IN MILES
4 2 0 4 8 12 16 20
LEGEND
DRAINAGE BOUNDARY
COUNTY BOUNDARY

CENTRAL PACIFIC BASINS PROJECT

PRIMARY STUDY AREA

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 2

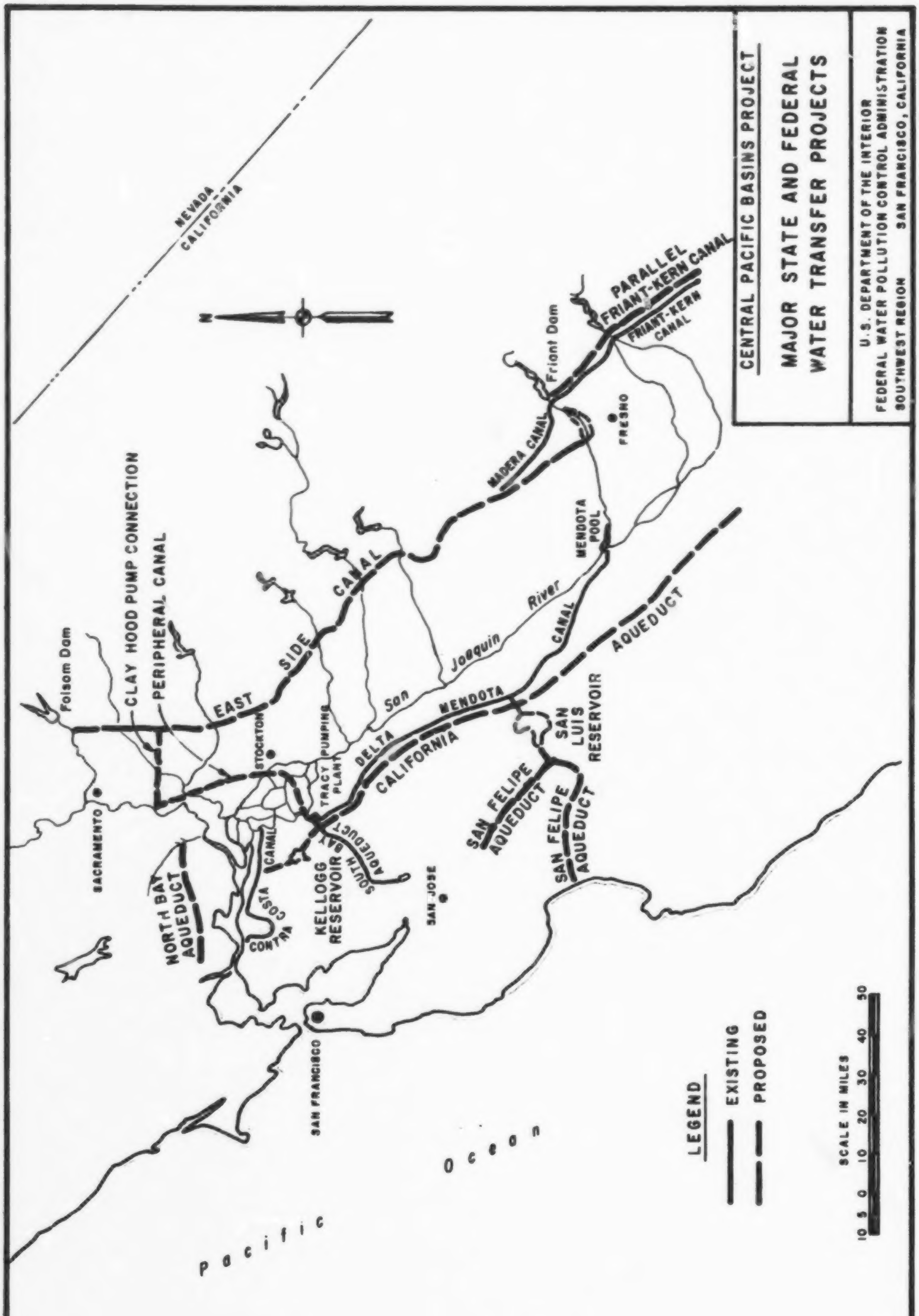
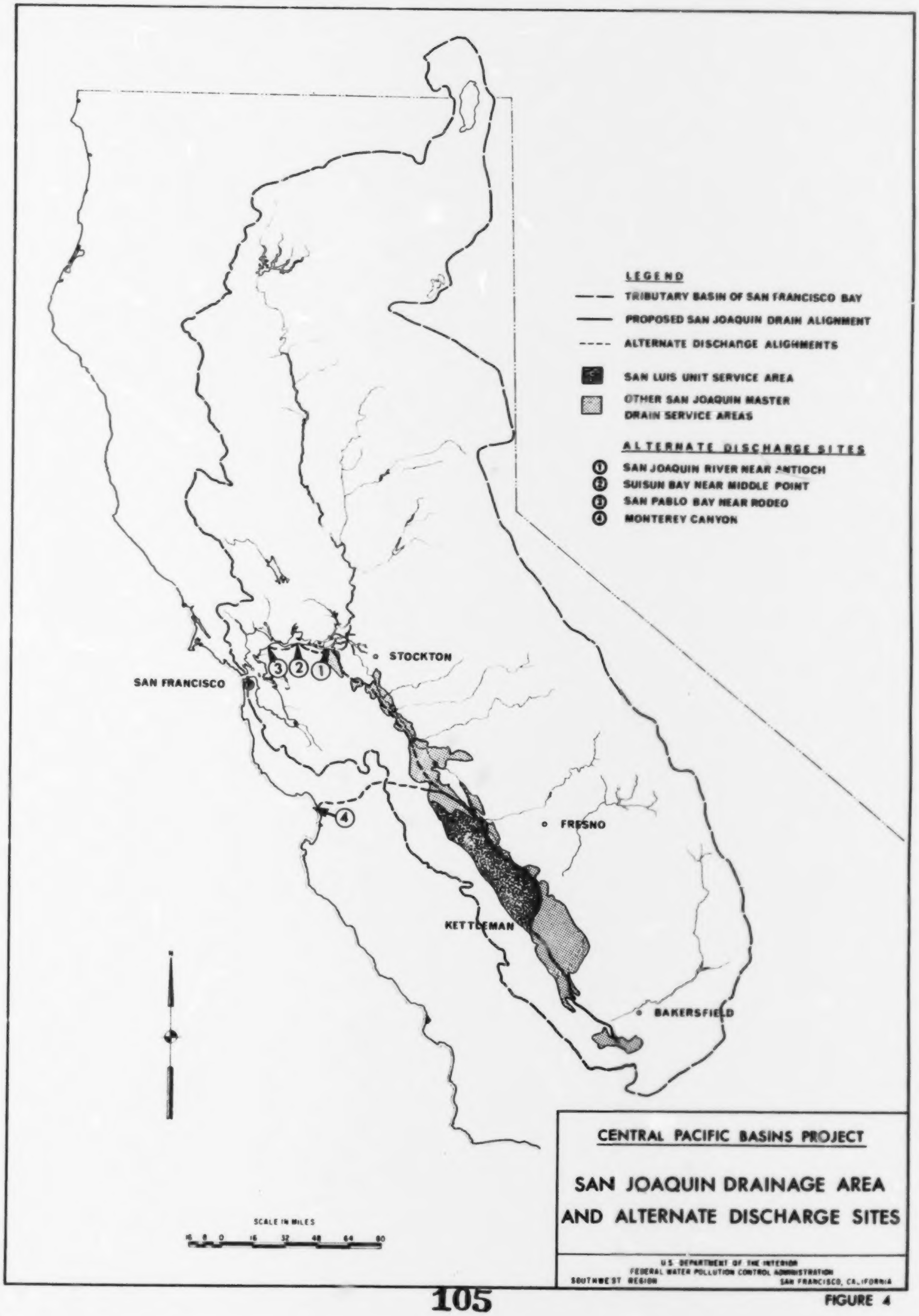

CENTRAL PACIFIC BASINS PROJECT
MAJOR STATE AND FEDERAL WATER TRANSFER PROJECTS
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
SAN FRANCISCO, CALIFORNIA
NEVADA
CALIFORNIA
N
PARALLEL FRIANT-KERN CANAL
FRIANT-KERN CANAL
Friant Dam
FRESNO
MADERA CANAL
MENDOTA POOL
EAST SIDE CANAL
CLAY HOOD PUMP CONNECTION
PERIPHERAL CANAL
Folsom Dam
SACRAMENTO
STOCKTON
PUMPING PLANT
TRACY
San Joaquin River
MENDOTA CANAL
DELTA
CALIFORNIA AQUEDUCT
SAN LUIS RESERVOIR
SAN FELIPE AQUEDUCT
SAN FELIPE AQUEDUCT
SOUTH BAY AQUEDUCT
KELLOGG RESERVOIR
CONTRA COSTA CANAL
NORTH BAY AQUEDUCT
SAN JOSE
SAN FRANCISCO
Pacific Ocean
LEGEND
EXISTING
PROPOSED
SCALE IN MILES
10 5 0 10 20 30 40 50

FIGURE 3

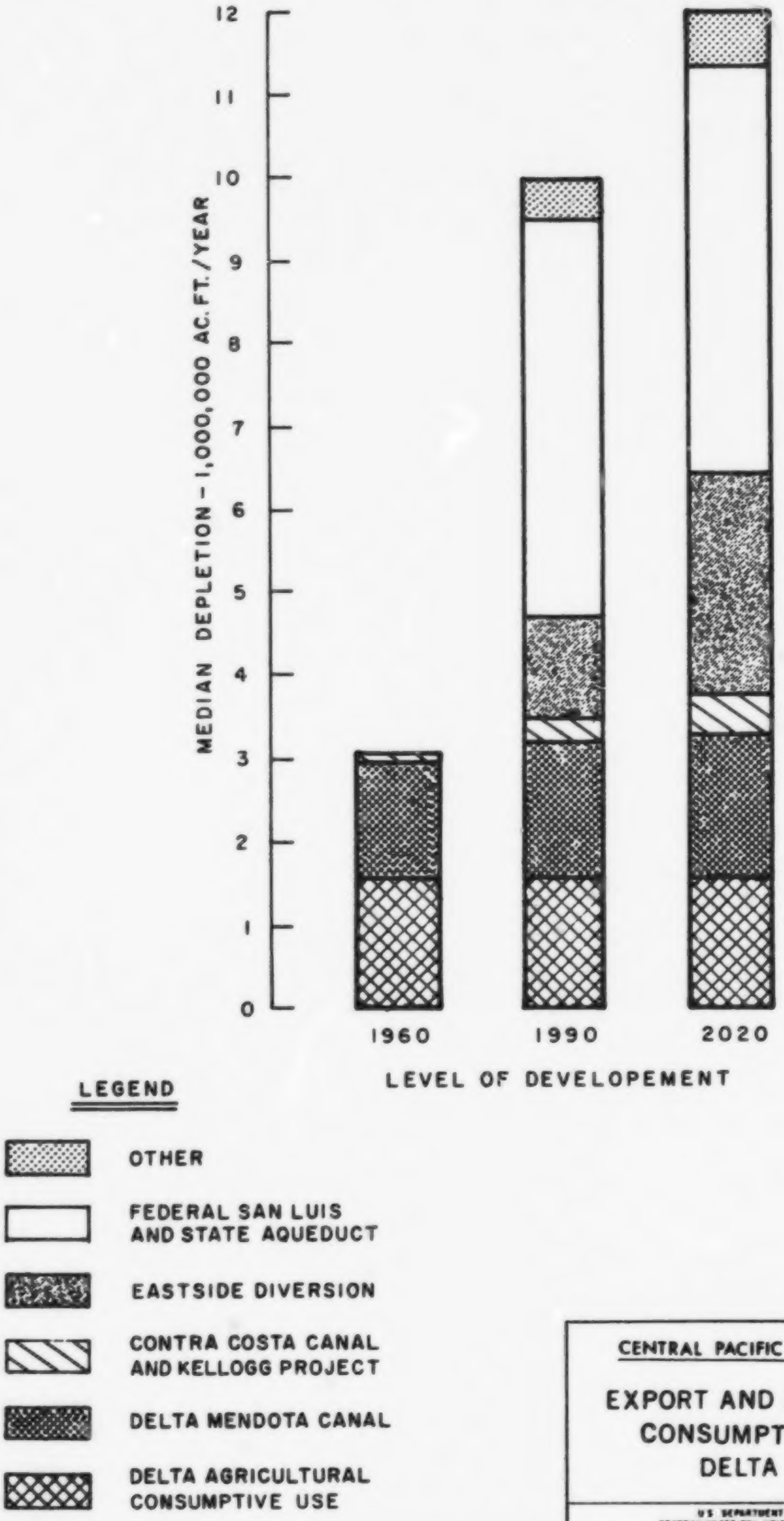

LEGEND
TRIBUTARY BASIN OF SAN FRANCISCO BAY
PROPOSED SAN JOAQUIN DRAIN ALIGNMENT
ALTERNATE DISCHARGE ALIGNMENTS
SAN LUIS UNIT SERVICE AREA
OTHER SAN JOAQUIN MASTER DRAIN SERVICE AREAS
ALTERNATE DISCHARGE SITES
① SAN JOAQUIN RIVER NEAR ANTIOCH
② SUISUN BAY NEAR MIDDLE POINT
③ SAN PABLO BAY NEAR RODEO
④ MONTEREY CANYON
STOCKTON
SAN FRANCISCO
FRESNO
KETTLEMAN
BAKERSFIELD
3
2
1
4
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

SAN JOAQUIN DRAINAGE AREA AND ALTERNATE DISCHARGE SITES

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 4

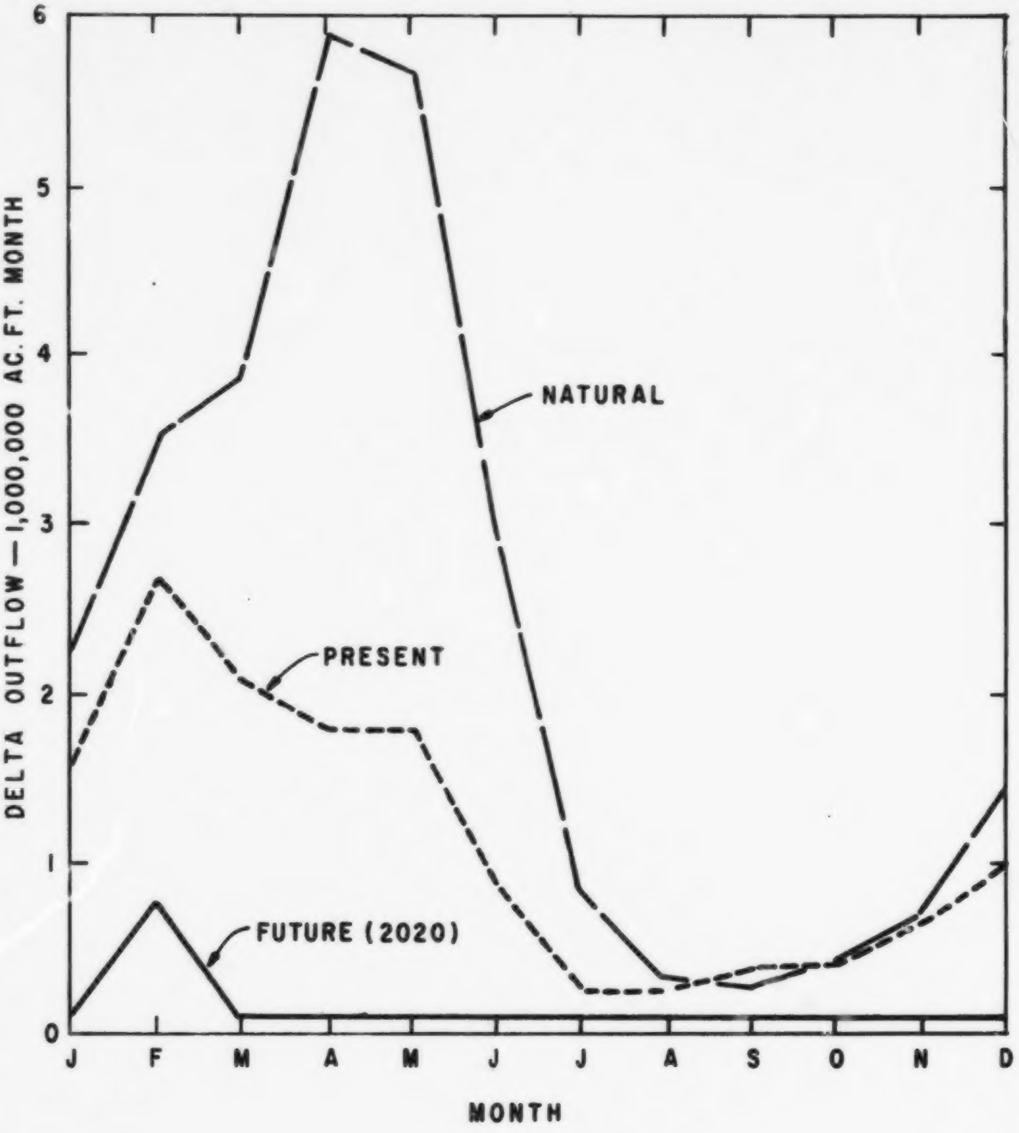


CENTRAL PACIFIC BASINS PROJECT

EXPORT AND AGRICULTURAL CONSUMPTIVE USE OF DELTA WATER

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 5

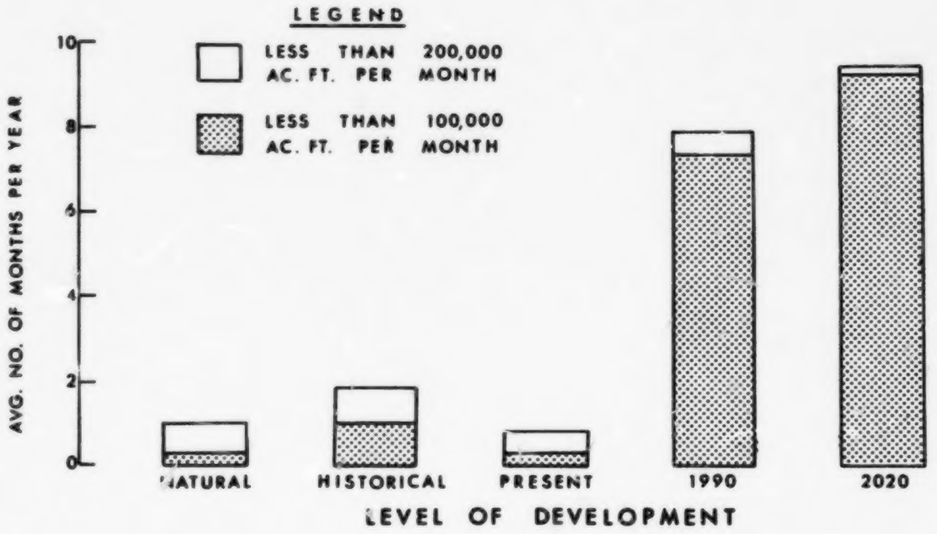


CENTRAL PACIFIC BASINS PROJECT

MEDIAN DELTA OUTFLOW

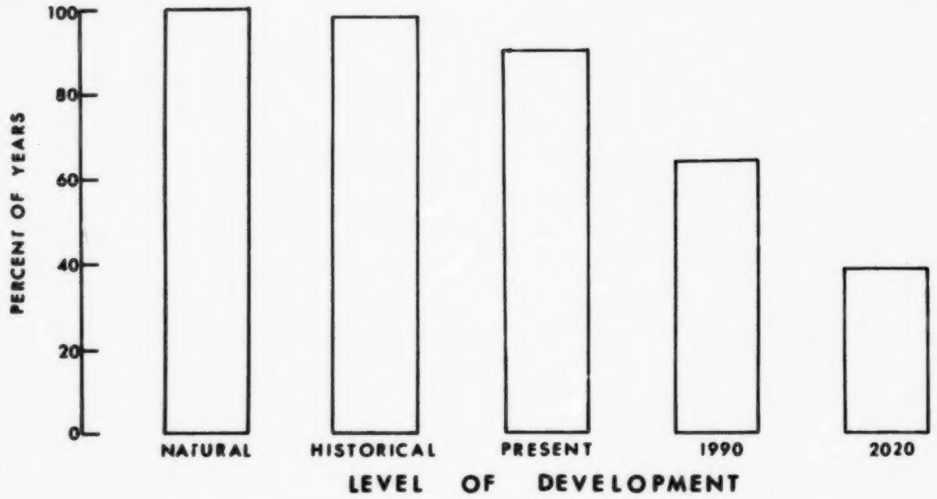
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 6



OCCURRENCE OF
LOW DELTA OUTFLOW

Figure 7



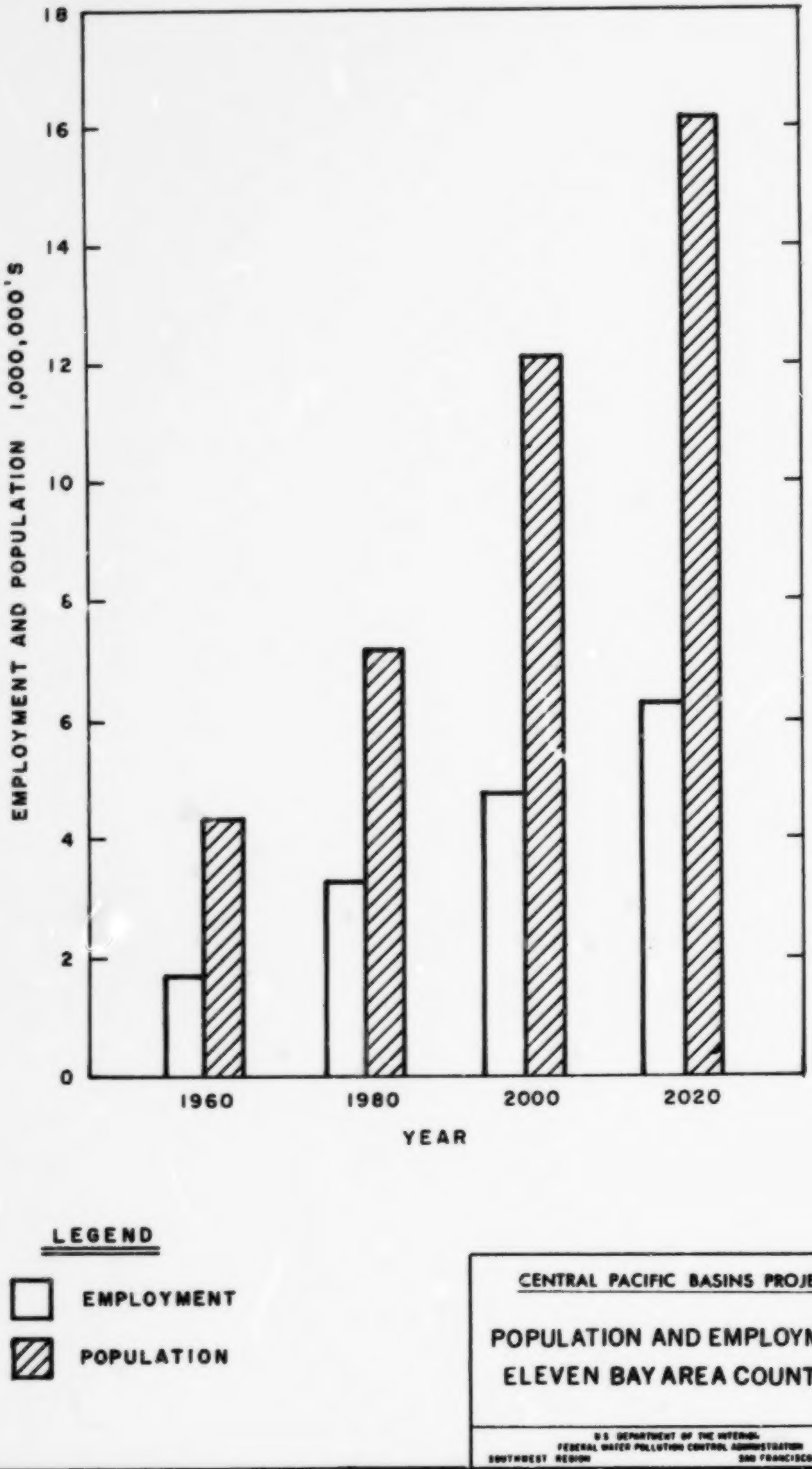
FREQUENCY OF DELTA OUTFLOWS
MEETING THE FLUSHING CRITERIA

Figure 8

CENTRAL PACIFIC BASINS PROJECT

U. S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURES 7 & 8

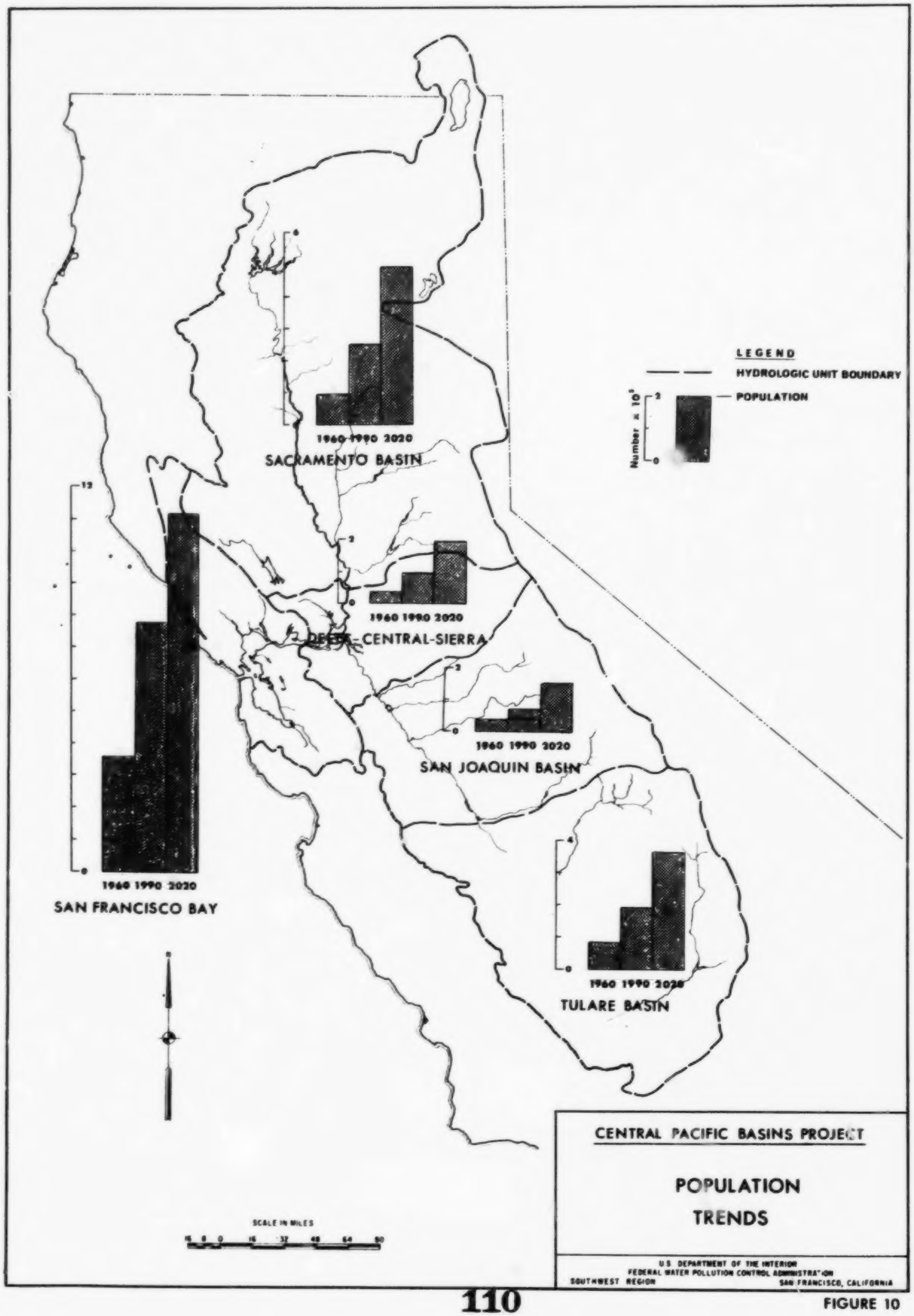


CENTRAL PACIFIC BASINS PROJECT

POPULATION AND EMPLOYMENT
ELEVEN BAY AREA COUNTIES

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 9



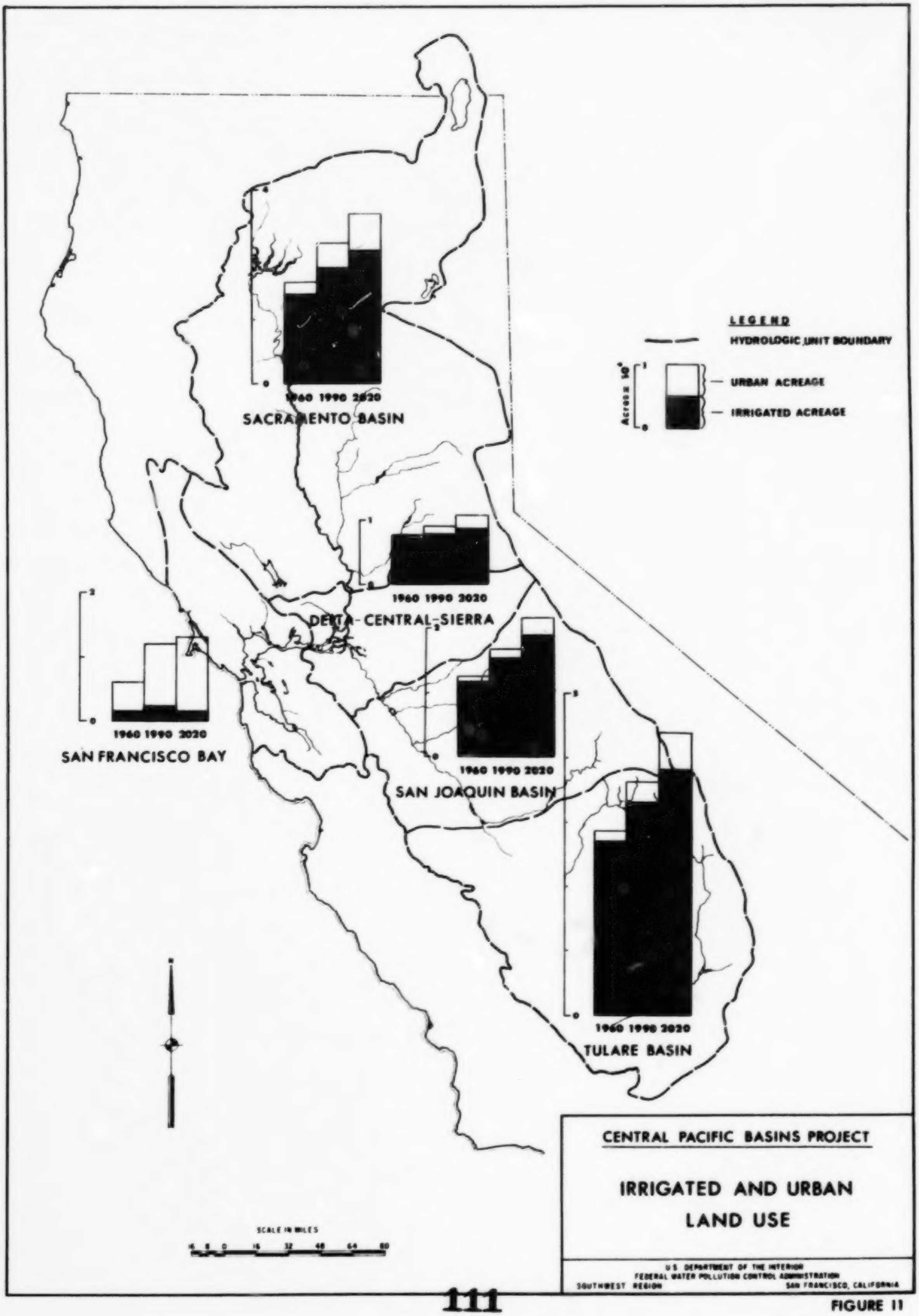
SACRAMENTO BASIN
1960 1990 2020
SAN FRANCISCO BAY
12
0
1960 1990 2020
DELTA-CENTRAL-SIERRA
2
0
1960 1990 2020
SAN JOAQUIN BASIN
2
0
1960 1990 2020
TULARE BASIN
4
0
1960 1990 2020
LEGEND
HYDROLOGIC UNIT BOUNDARY
POPULATION
Number x 10^6
2
0
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

POPULATION
TRENDS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 10

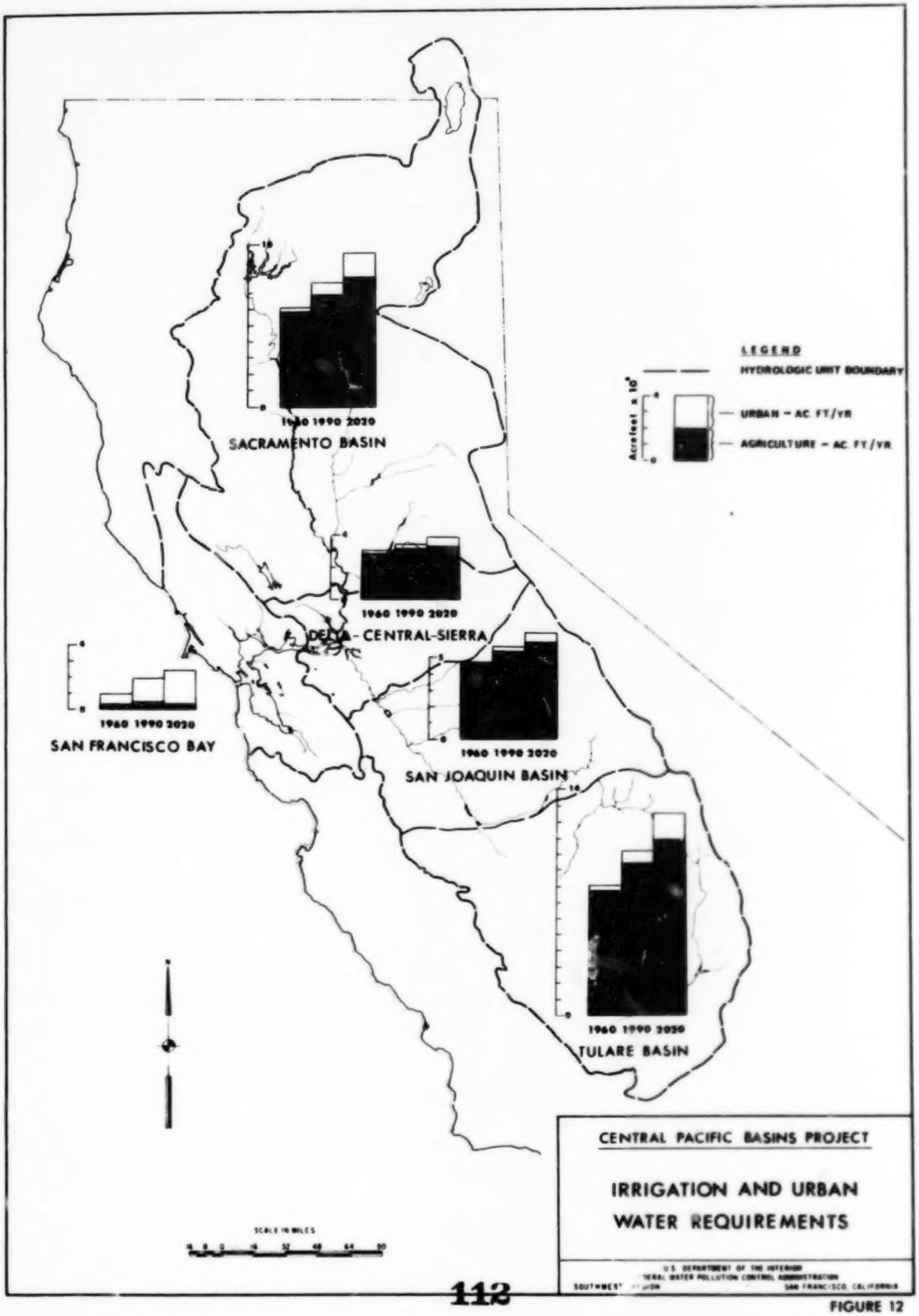

LEGEND
HYDROLOGIC UNIT BOUNDARY
Acreage 10⁶
1
0
URBAN ACREAGE
IRRIGATED ACREAGE
4
0
1960 1990 2020
SACRAMENTO BASIN
1
0
1960 1990 2020
DELTA-CENTRAL-SIERRA
2
0
1960 1990 2020
SAN FRANCISCO BAY
2
0
1960 1990 2020
SAN JOAQUIN BASIN
3
0
1960 1990 2020
TULARE BASIN
N
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

IRRIGATED AND URBAN
LAND USE

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 11

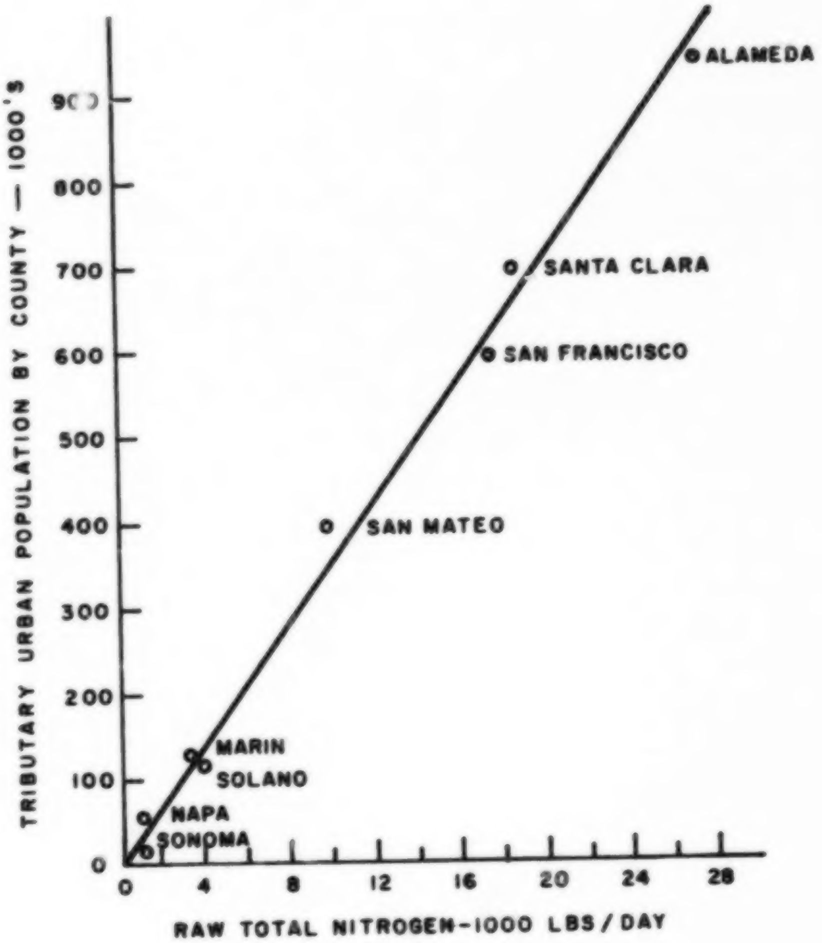

1960 1990 2020
SACRAMENTO BASIN
1960 1990 2020
DELTA-CENTRAL-SIERRA
1960 1990 2020
SAN FRANCISCO BAY
1960 1990 2020
SAN JOAQUIN BASIN
1960 1990 2020
TULARE BASIN
LEGEND
HYDROLOGIC UNIT BOUNDARY
Acrefeet x 10⁶
URBAN - AC FT/YR
AGRICULTURE - AC FT/YR
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

IRRIGATION AND URBAN
WATER REQUIREMENTS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 12

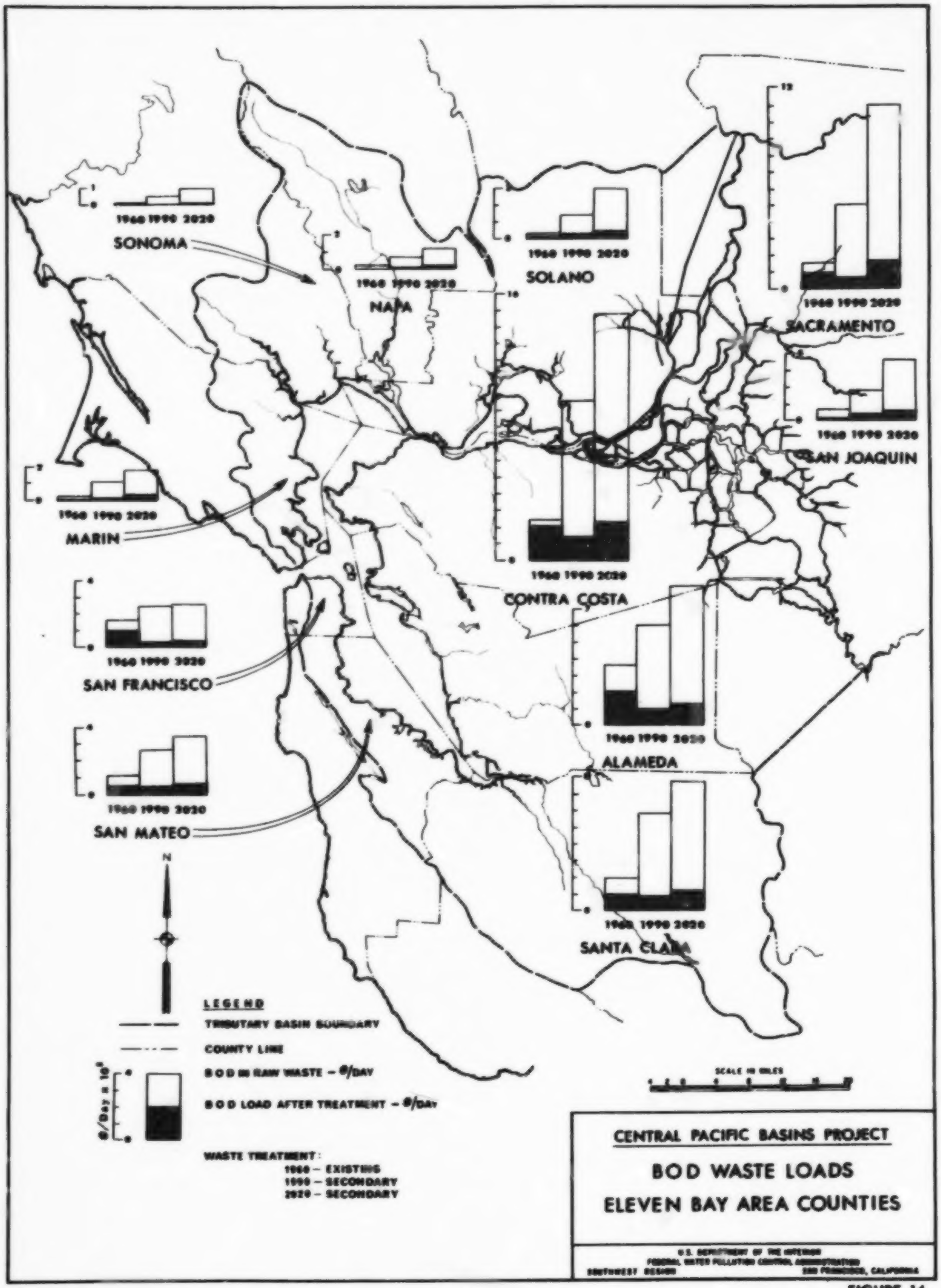


CENTRAL PACIFIC BASINS PROJECT

RAW NITROGEN WASTE LOAD
SAN FRANCISCO BAY COUNTIES

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 13



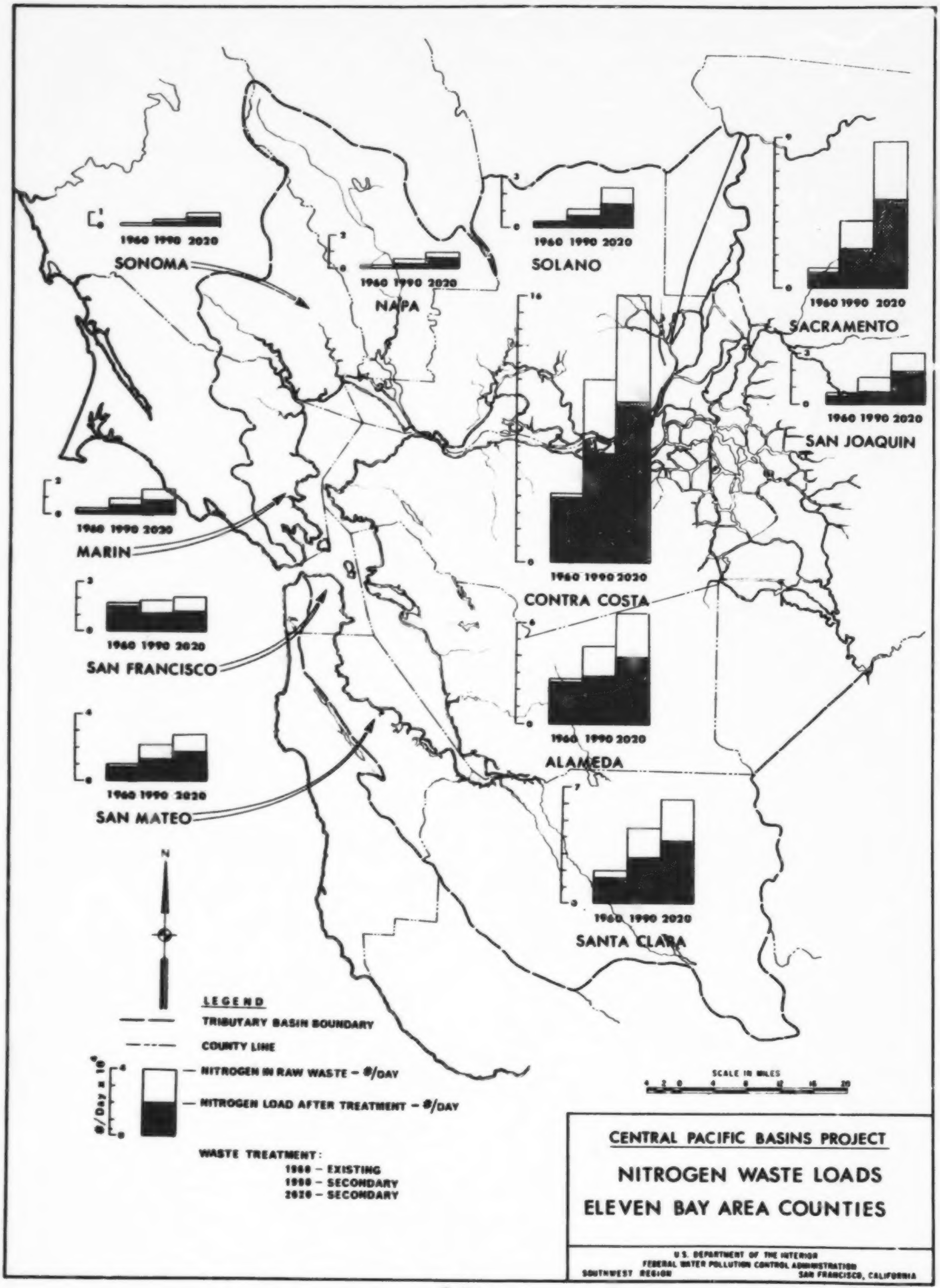
SONOMA
NAPA
SOLANO
SACRAMENTO
SAN JOAQUIN
MARIN
CONTRA COSTA
SAN FRANCISCO
ALAMEDA
SAN MATEO
SANTA CLARA
1960 1990 2020
N
LEGEND
TRIBUTARY BASIN BOUNDARY
COUNTY LINE
BOD IN RAW WASTE – #/DAY
BOD LOAD AFTER TREATMENT – #/DAY
#/Day x 10³
WASTE TREATMENT:
1960 – EXISTING
1990 – SECONDARY
2020 – SECONDARY
SCALE IN MILES

CENTRAL PACIFIC BASINS PROJECT

BOD WASTE LOADS
ELEVEN BAY AREA COUNTIES

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 14

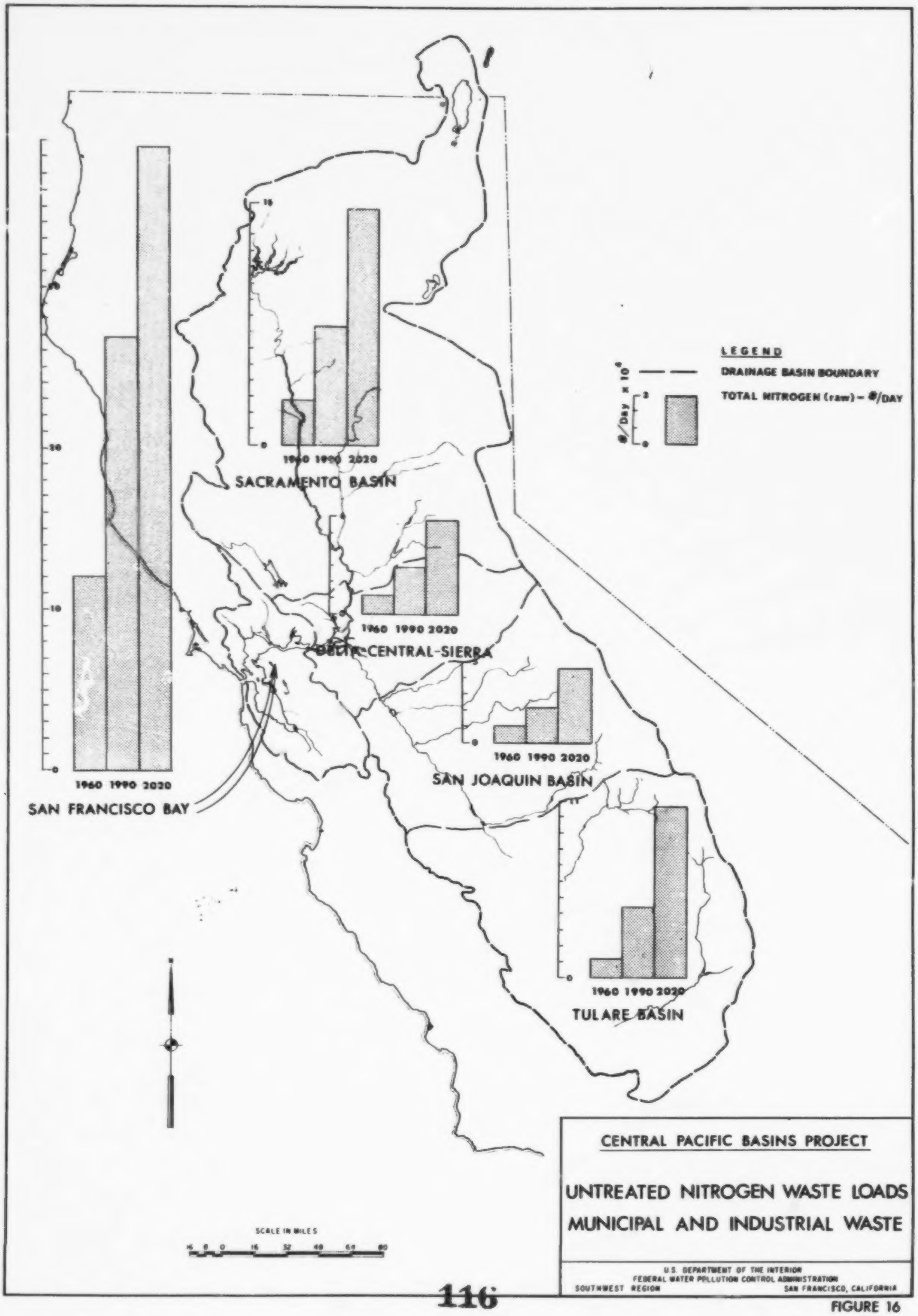

1
0
1960 1990 2020
SONOMA
2
0
1960 1990 2020
NAPA
3
0
1960 1990 2020
SOLANO
0
1960 1990 2020
SACRAMENTO
16
0
1960 1990 2020
CONTRA COSTA
3
0
1960 1990 2020
SAN JOAQUIN
2
0
1960 1990 2020
MARIN
3
0
1960 1990 2020
SAN FRANCISCO
6
0
1960 1990 2020
ALAMEDA
4
0
1960 1990 2020
SAN MATEO
7
0
1960 1990 2020
SANTA CLARA
N
LEGEND
TRIBUTARY BASIN BOUNDARY
COUNTY LINE
#/Day x 10^4
4
0
NITROGEN IN RAW WASTE – #/DAY
NITROGEN LOAD AFTER TREATMENT – #/DAY
WASTE TREATMENT:
1960 – EXISTING
1990 – SECONDARY
2020 – SECONDARY
SCALE IN MILES
4 2 0 4 8 12 16 20

CENTRAL PACIFIC BASINS PROJECT

NITROGEN WASTE LOADS
ELEVEN BAY AREA COUNTIES

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 15

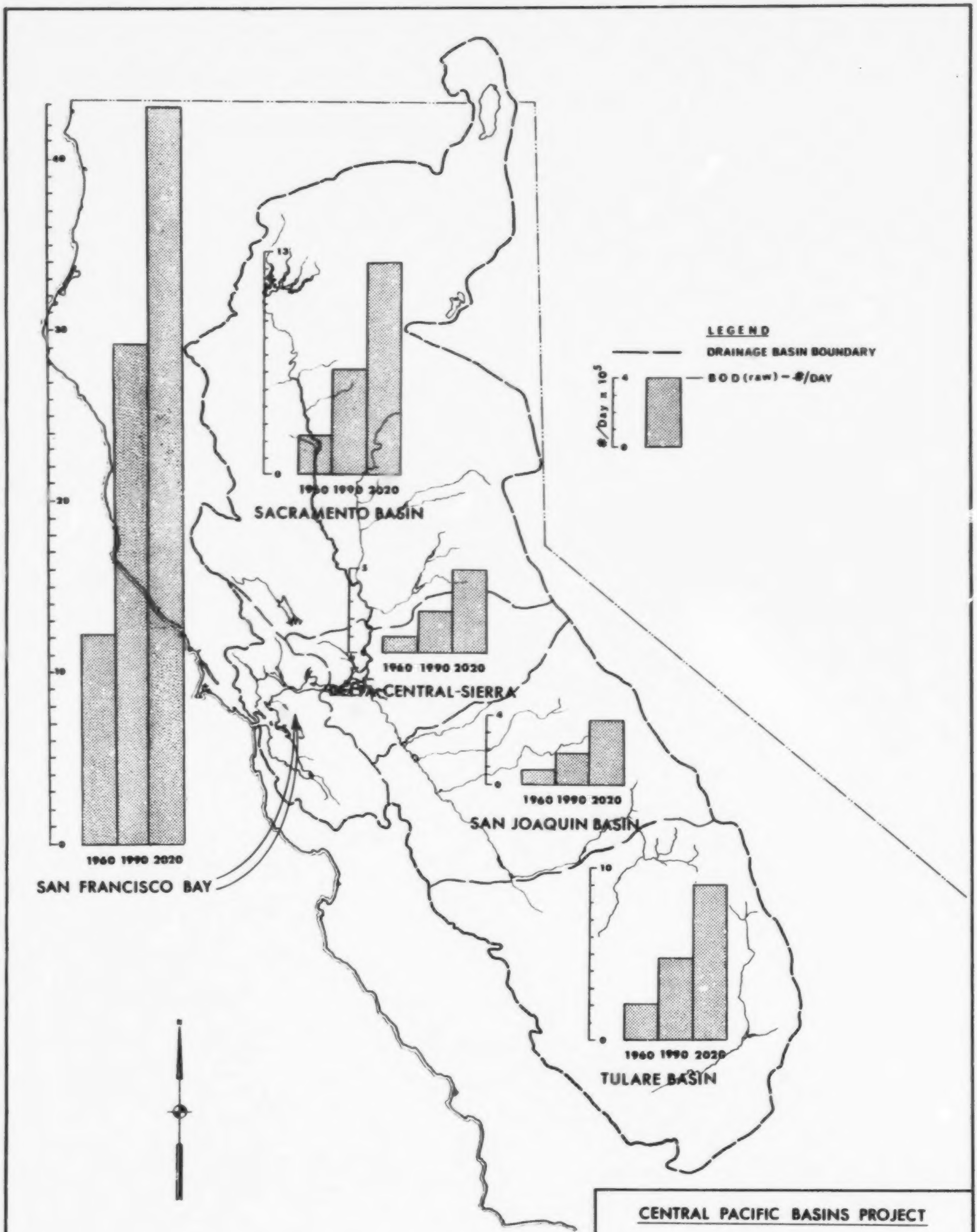

LEGEND
DRAINAGE BASIN BOUNDARY
TOTAL NITROGEN (raw) - #/DAY
#/Day x 10⁴
3
0
SACRAMENTO BASIN
10
0
1960 1990 2020
DELTA-CENTRAL-SIERRA
1960 1990 2020
SAN JOAQUIN BASIN
5
0
1960 1990 2020
TULARE BASIN
0
1960 1990 2020
SAN FRANCISCO BAY
20
10
0
1960 1990 2020
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

UNTREATED NITROGEN WASTE LOADS
MUNICIPAL AND INDUSTRIAL WASTE

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 16

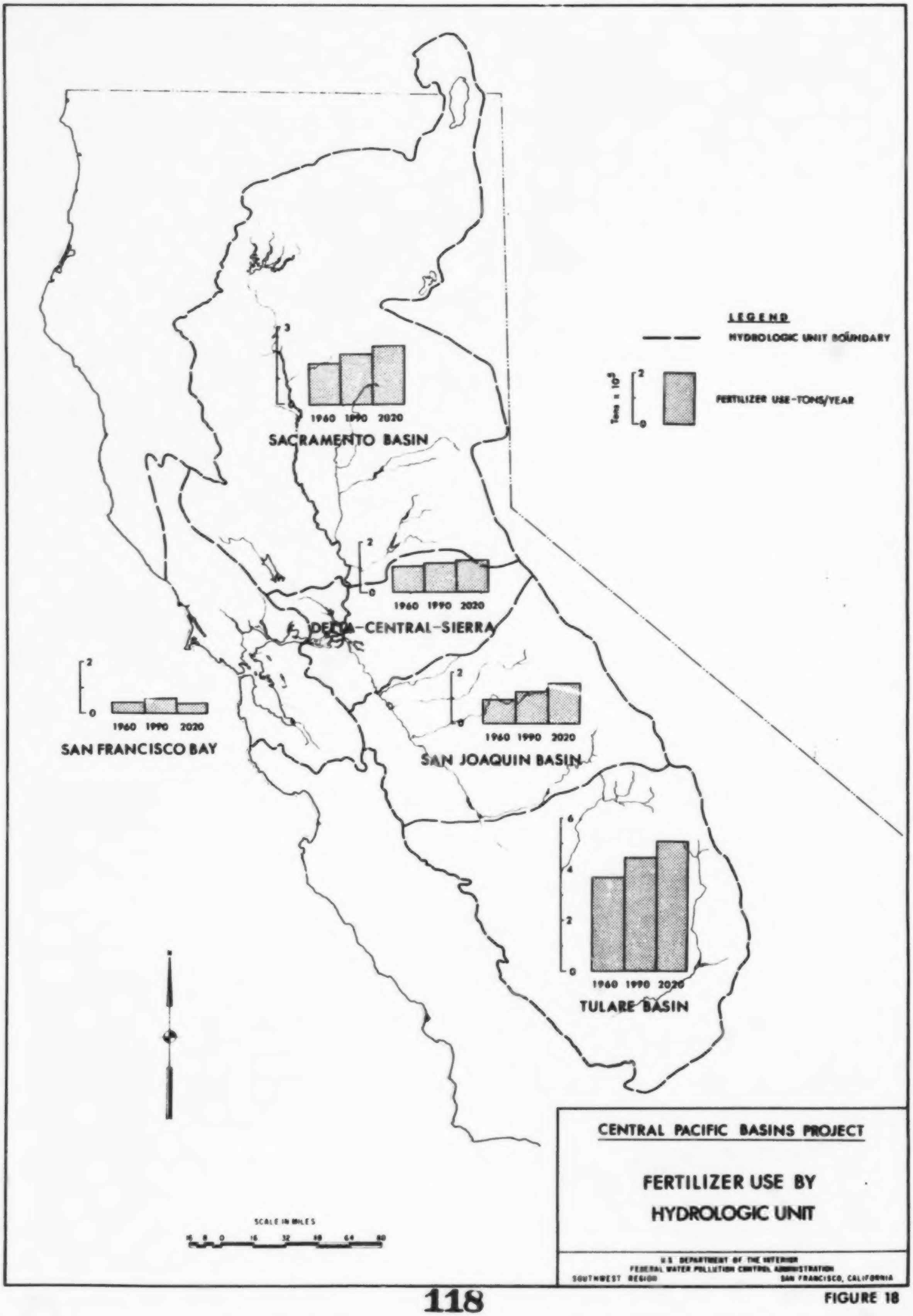

LEGEND
DRAINAGE BASIN BOUNDARY
B O D (raw) — #/DAY
#/Day x 10⁵
4
0
SACRAMENTO BASIN
13
0
1960 1990 2020
DELTA-CENTRAL-SIERRA
5
1960 1990 2020
SAN JOAQUIN BASIN
4
0
1960 1990 2020
TULARE BASIN
10
0
1960 1990 2020
SAN FRANCISCO BAY
40
30
20
10
0
1960 1990 2020
N
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

UNTREATED BOD WASTE LOADS
MUNICIPAL AND INDUSTRIAL WASTE

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 17

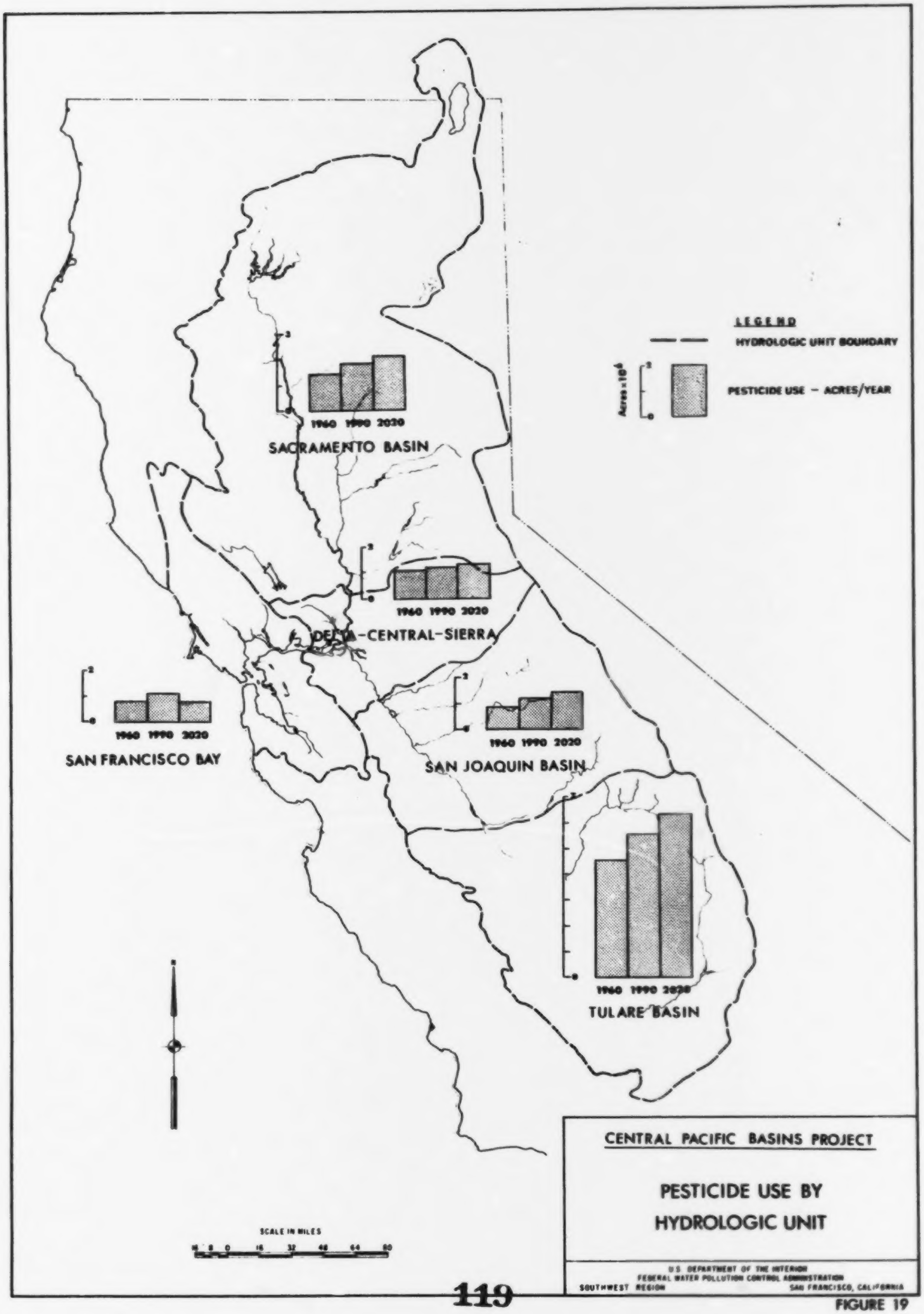

LEGEND
HYDROLOGIC UNIT BOUNDARY
Tons x 10³
2
0
FERTILIZER USE-TONS/YEAR
3
1960 1990 2020
SACRAMENTO BASIN
2
0
1960 1990 2020
DELTA-CENTRAL-SIERRA
2
0
1960 1990 2020
SAN FRANCISCO BAY
2
0
1960 1990 2020
SAN JOAQUIN BASIN
6
4
2
0
1960 1990 2020
TULARE BASIN
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

FERTILIZER USE BY
HYDROLOGIC UNIT

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 18

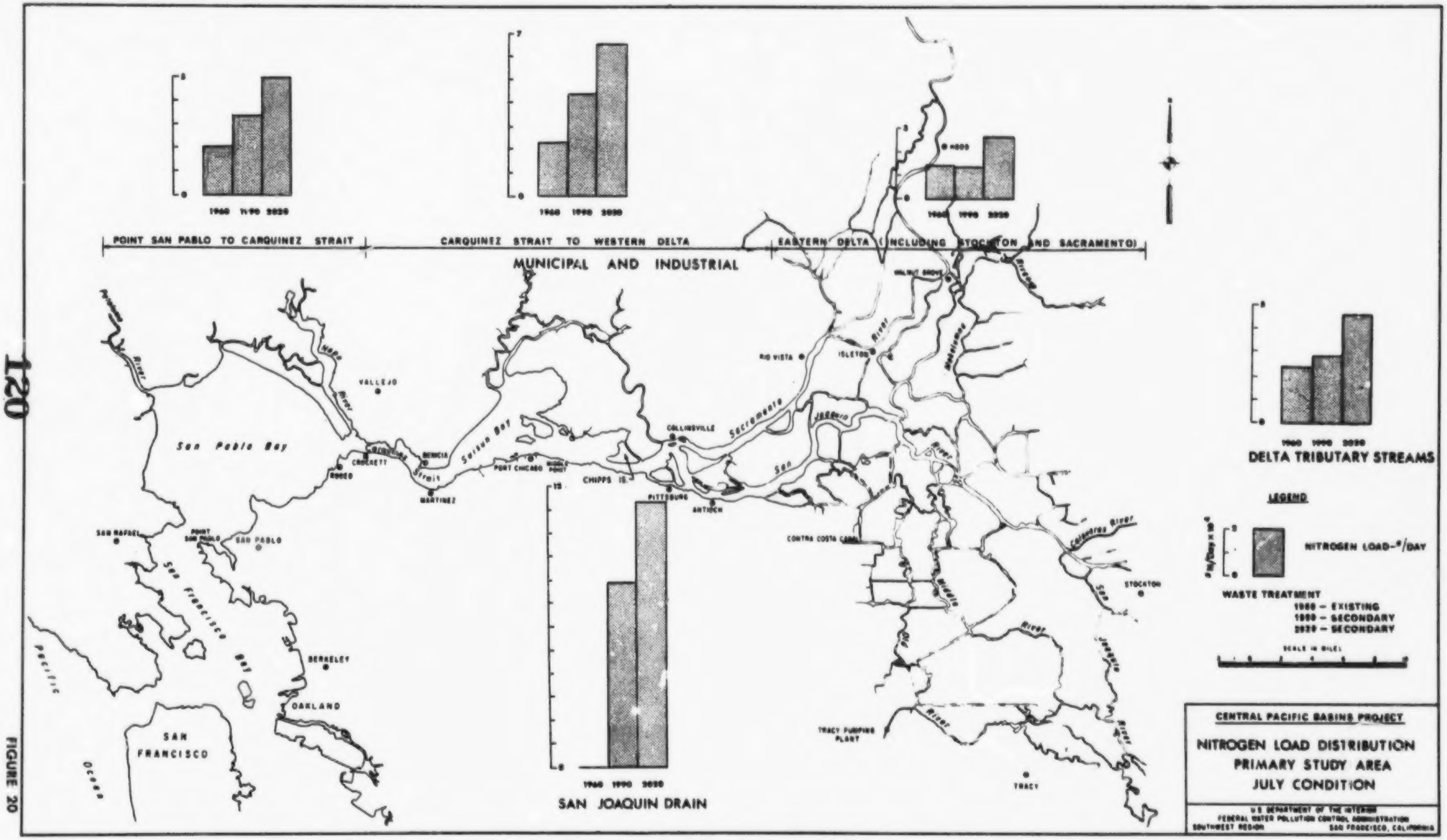

LEGEND
HYDROLOGIC UNIT BOUNDARY
Acres x 10⁶
2
0
PESTICIDE USE – ACRES/YEAR
SACRAMENTO BASIN
DELTA-CENTRAL-SIERRA
SAN FRANCISCO BAY
SAN JOAQUIN BASIN
TULARE BASIN
1960 1990 2020
N
SCALE IN MILES
16 8 0 16 32 48 64 80

CENTRAL PACIFIC BASINS PROJECT

PESTICIDE USE BY
HYDROLOGIC UNIT

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 19



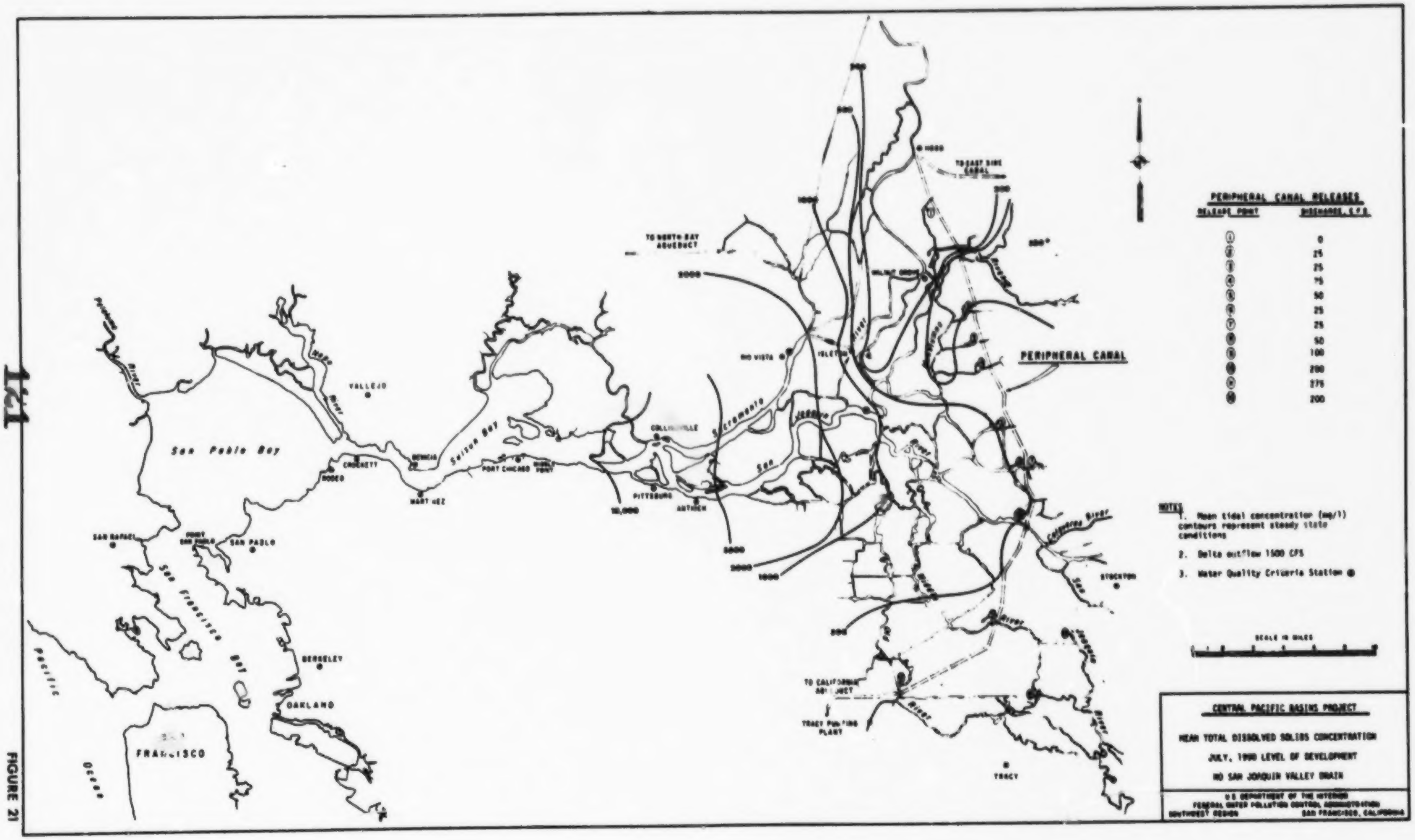
POINT SAN PABLO TO CARQUINEZ STRAIT
CARQUINEZ STRAIT TO WESTERN DELTA
EASTERN DELTA (INCLUDING STOCKTON AND SACRAMENTO)
MUNICIPAL AND INDUSTRIAL
1960
1990
2020
0
5
7
DELTA TRIBUTARY STREAMS
SAN JOAQUIN DRAIN
15
LEGEND
NITROGEN LOAD-#/DAY
WASTE TREATMENT
1960 – EXISTING
1990 – SECONDARY
2020 – SECONDARY
SCALE IN MILES
San Pablo Bay
San Francisco Bay
SAN FRANCISCO
Pacific Ocean
Petaluma River
Napa River
Carquinez Strait
Suisun Bay
Sacramento River
San Joaquin River
Mokelumne River
Cosumnes River
Calaveras River
Middle River
Old River
SAN RAFAEL
POINT SAN PABLO
SAN PABLO
BERKELEY
OAKLAND
VALLEJO
RODEO
CROCKETT
BENICIA
MARTINEZ
PORT CHICAGO
CHIPPS IS.
PITTSBURG
ANTIOCH
COLLINSVILLE
RIO VISTA
ISLETON
WALNUT GROVE
HOOD
CONTRA COSTA CANAL
TRACY PUMPING PLANT
TRACY
STOCKTON

CENTRAL PACIFIC BASINS PROJECT

NITROGEN LOAD DISTRIBUTION
PRIMARY STUDY AREA
JULY CONDITION

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 20


PERIPHERAL CANAL
TO NORTH BAY AQUEDUCT
TO EAST SIDE CANAL
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
HOOD
WALNUT GROVE
ISLETON
RIO VISTA
COLLINSVILLE
PITTSBURG
ANTIOCH
STOCKTON
TRACY
Sacramento
San Joaquin
Calaveras River
River
PORT CHICAGO
MARTINEZ
BENICIA
CROCKETT
RODEO
VALLEJO
Suisun Bay
San Pablo Bay
SAN RAFAEL
POINT SAN PABLO
SAN PABLO
BERKELEY
OAKLAND
San Francisco Bay
FRANCISCO
Pacific
Ocean
10,000
5000
3000
2000
1000
500
SCALE IN MILES

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, C.F.S.
①	0
②	25
③	25
④	75
⑤	50
⑥	25
⑦	25
⑧	50
⑨	100
⑩	200
⑪	275
⑫	200

NOTES:

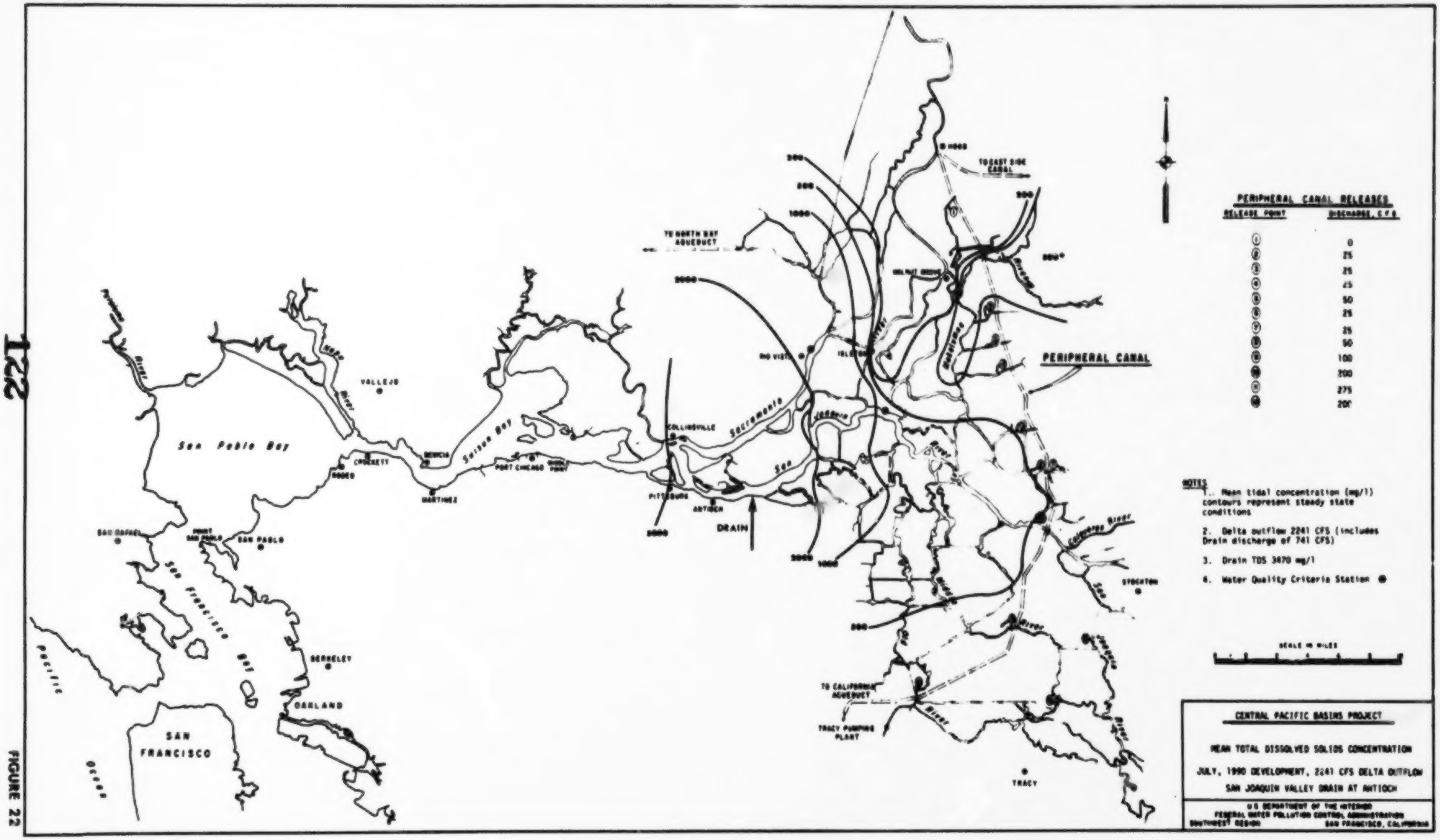
1. Mean tidal concentration (mg/l) contours represent steady state conditions
2. Delta outflow 1500 CFS
3. Water Quality Criteria Station ●

CENTRAL PACIFIC BASINS PROJECT

MEAN TOTAL DISSOLVED SOLIDS CONCENTRATION
JULY, 1990 LEVEL OF DEVELOPMENT
NO SAN JOAQUIN VALLEY DRAIN

U S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 21


San Pablo Bay
Vallejo
Napa River
Petaluma River
Rodeo
Crockett
Benicia
Martinez
Suisun Bay
Port Chicago
Collinsville
Pittsburg
Antioch
DRAIN
Sacramento
San
Joaquin
Rio Vista
Isleton
Walnut Grove
Hood
TO EAST SIDE CANAL
TO NORTH BAY AQUEDUCT
PERIPHERAL CANAL
Stockton
Calaveras River
San Joaquin River
Old River
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
Tracy
San Rafael
Point San Pablo
San Pablo
Berkeley
Oakland
San Francisco Bay
SAN FRANCISCO
Pacific Ocean
200
500
1000
2000
3000
SCALE IN MILES

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, C F S
①	0
②	25
③	25
④	25
⑤	50
⑥	25
⑦	25
⑧	50
⑨	100
⑩	200
⑪	275
⑫	200

NOTES

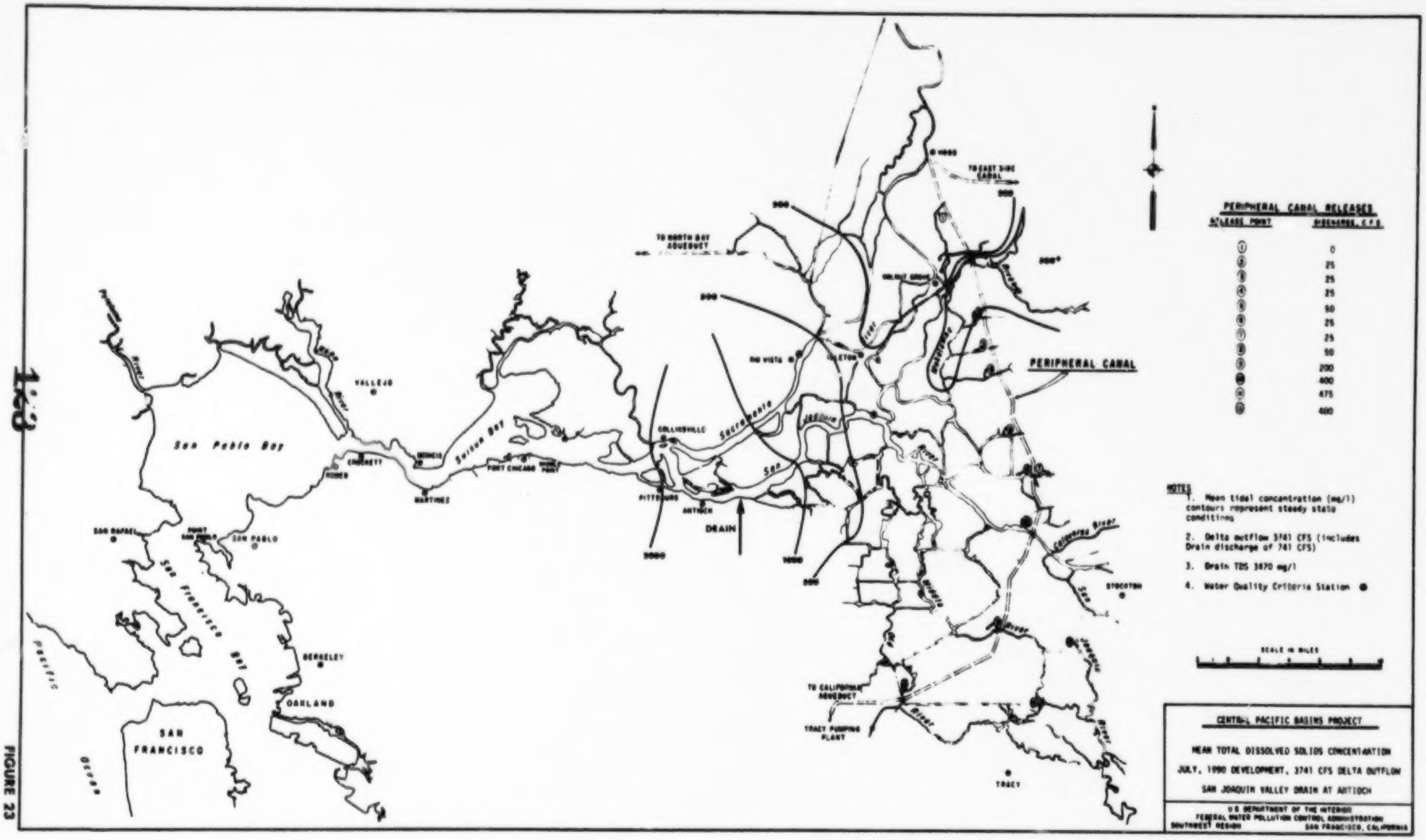
1. Mean tidal concentration (mg/1) contours represent steady state conditions
2. Delta outflow 2241 CFS (includes Drain discharge of 741 CFS)
3. Drain TDS 3470 mg/1
4. Water Quality Criteria Station ●

CENTRAL PACIFIC BASINS PROJECT

MEAN TOTAL DISSOLVED SOLIDS CONCENTRATION
JULY, 1990 DEVELOPMENT, 2241 CFS DELTA OUTFLOW
SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 22



San Pablo Bay
Suisun Bay
San Francisco Bay
Pacific
Ocean
SAN FRANCISCO
OAKLAND
BERKELEY
SAN PABLO
SAN RAFAEL
VALLEJO
CROCKETT
RODEO
BENICIA
MARTINEZ
PORT CHICAGO
PITTSBURG
ANTIOCH
COLLINSVILLE
DRAIN
RIO VISTA
ISLETON
WALNUT GROVE
Sacramento
San Joaquin
STOCKTON
TRACY
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
TO NORTH BAY AQUEDUCT
TO EAST SIDE CANAL
PERIPHERAL CANAL
5000
1000
500
300
200
SCALE IN MILES

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, C.F.S.
①	0
②	25
③	25
④	25
⑤	50
⑥	25
⑦	25
⑧	50
⑨	200
⑩	400
⑪	475
⑫	600

NOTES

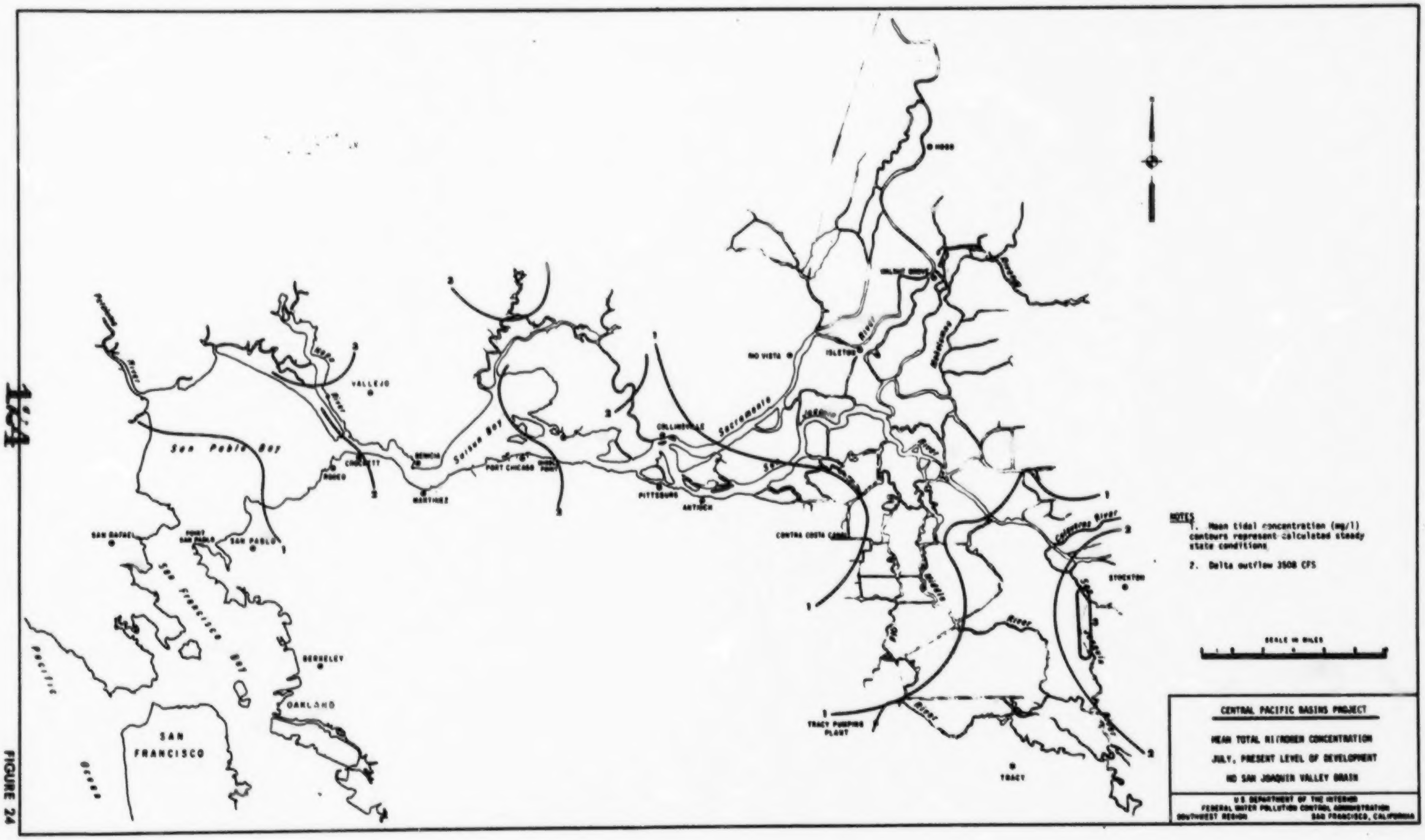
1. Mean tidal concentration (mg/l) contours represent steady state conditions
2. Delta outflow 3741 CFS (includes Drain discharge of 741 CFS)
3. Drain TDS 3470 mg/l
4. Water Quality Criteria Station ●

CENTRAL PACIFIC BASINS PROJECT

MEAN TOTAL DISSOLVED SOLIDS CONCENTRATION
JULY, 1990 DEVELOPMENT, 3741 CFS DELTA OUTFLOW
SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 23


Petaluma River
Napa River
Vallejo
San Pablo Bay
Rodeo
Crockett
Benicia
Martinez
Suisun Bay
Port Chicago
Pittsburg
Antioch
Collinsville
Sacramento River
Rio Vista
Isleton
Walnut Grove
Hood
Mokelumne River
Contra Costa Canal
Calaveras River
Stockton
San Joaquin River
Old River
Middle River
Tracy Pumping Plant
Tracy
San Rafael
Point San Pablo
San Pablo
Berkeley
Oakland
San Francisco Bay
San Francisco
Pacific Ocean
SCALE IN MILES
1
2
3

NOTES
1. Mean tidal concentration (mg/l) contours represent calculated steady state conditions
2. Delta outflow 3508 CFS

CENTRAL PACIFIC BASINS PROJECT

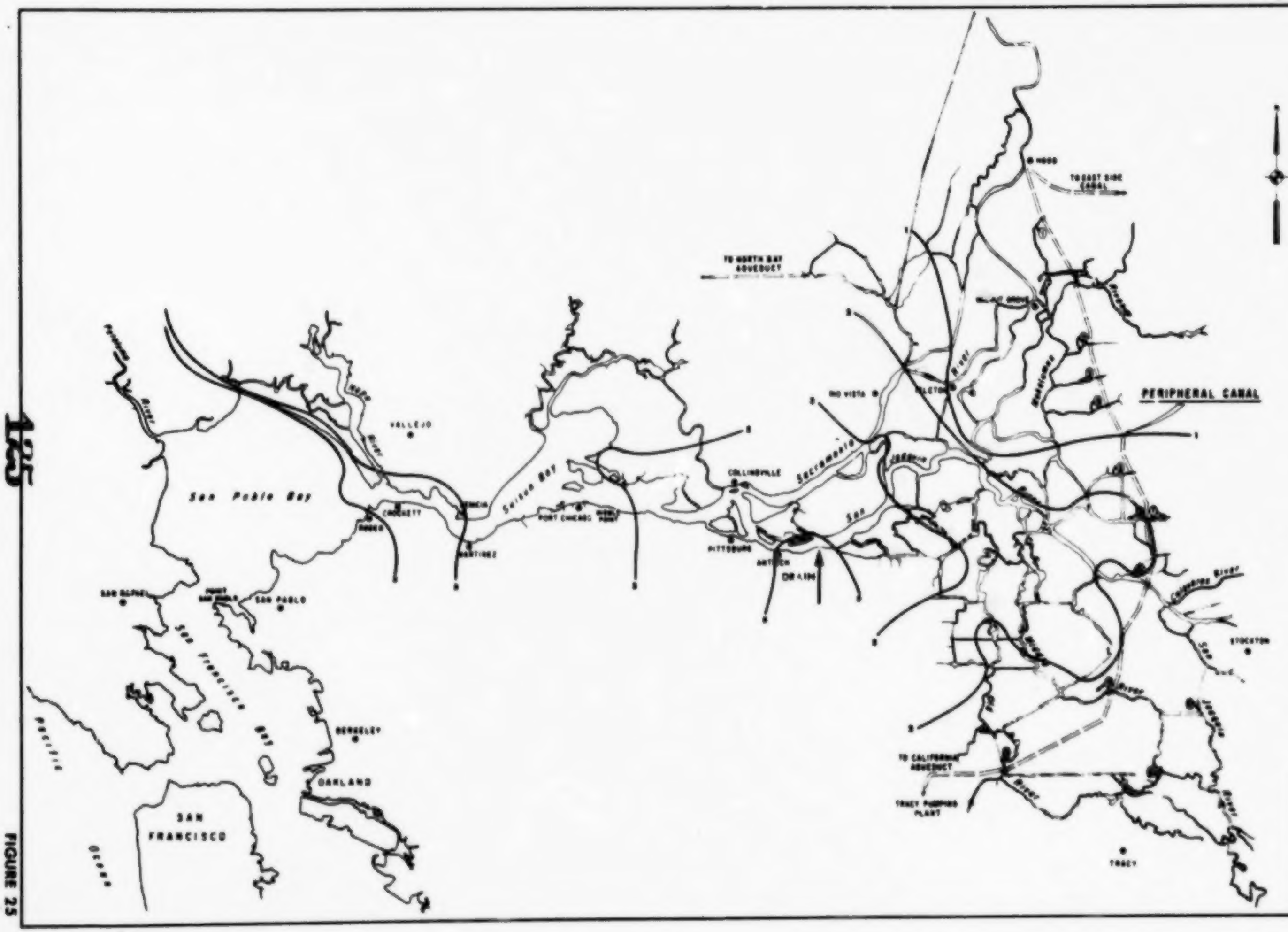
MEAN TOTAL NITROGEN CONCENTRATION

JULY, PRESENT LEVEL OF DEVELOPMENT

NO SAN JOAQUIN VALLEY DRAIN

U S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 24


Petaluma River
Napa River
Vallejo
San Pablo Bay
Rodeo
Crockett
Benicia
Martinez
Suisun Bay
Port Chicago
Collinsville
Pittsburg
Antioch
DRAIN
Sacramento
San
Joaquin
Rio Vista
Isleton
River
Walnut Grove
Hood
TO EAST SIDE CANAL
TO NORTH BAY AQUEDUCT
Mokelumne
PERIPHERAL CANAL
Calaveras River
Stockton
San Joaquin River
Old
River
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
Tracy
San Rafael
Point San Pablo
San Pablo
San Francisco Bay
Berkeley
Oakland
SAN FRANCISCO
Pacific Ocean

PERIPHER'L CANAL RELEASES

RELEASE POINT	DISCHARGE, C.F.S.
①	0
②	25
③	25
④	25
⑤	50
⑥	25
⑦	25
⑧	50
⑨	200
⑩	400
⑪	475
⑫	400

NOTES

1. Mean tidal concentration (mg/l) contours represent steady state conditions
2. Delta outflow 3740 CFS (includes Drain discharge of 440 CFS)
3. Drain nitrogen concentration 21 mg/l

SCALE IN MILES

CENTRAL PACIFIC BASINS PROJECT

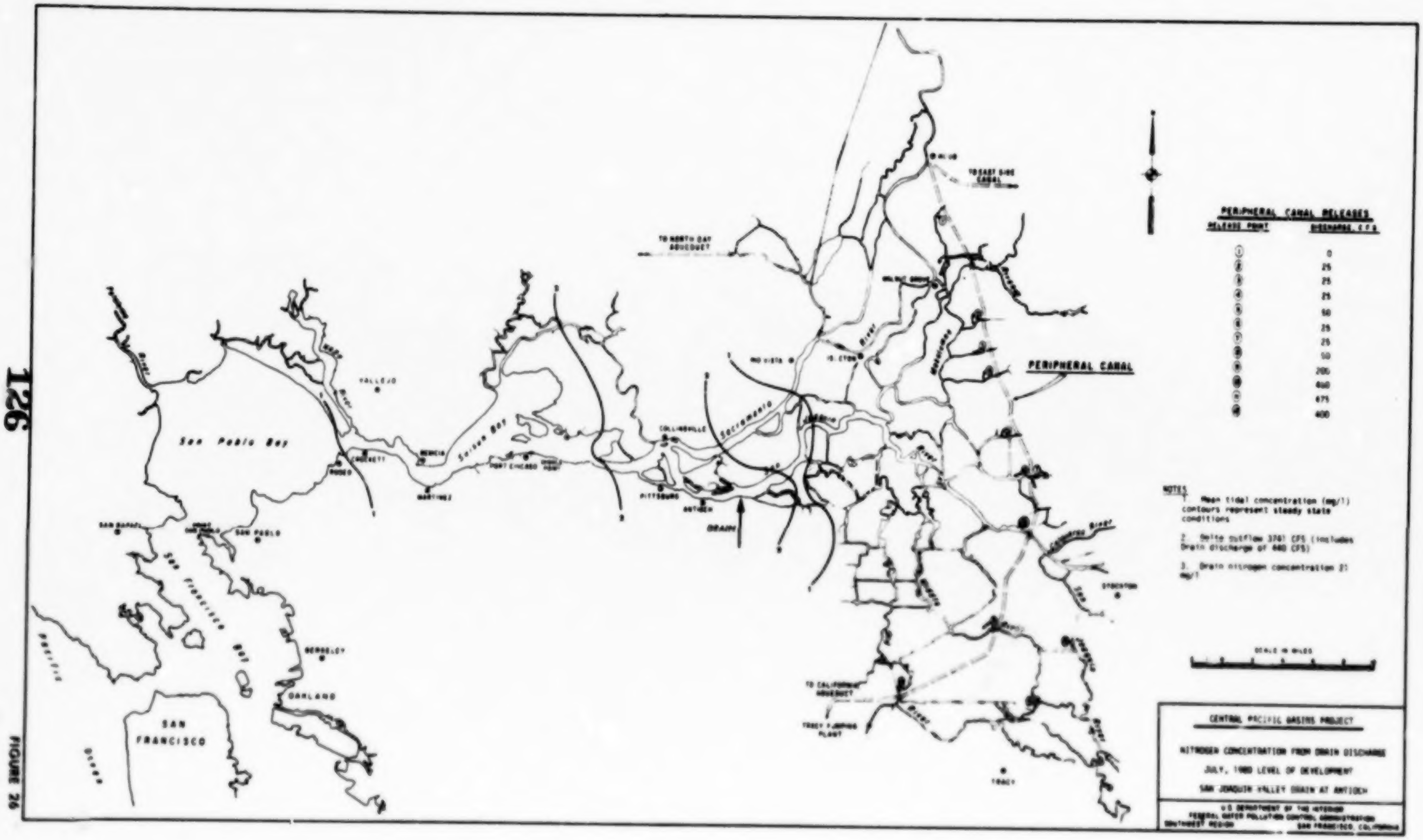
MEAN TOTAL NITROGEN CONCENTRATION

JULY, 1980 LEVEL OF DEVELOPMENT

SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 25


San Pablo Bay
San Francisco Bay
Suisun Bay
Sacramento
River
SAN FRANCISCO
Pacific
Ocean
VALLEJO
CROCKETT
RODEO
BENICIA
MARTINEZ
PORT CHICAGO
PITTSBURG
ANTIOCH
COLLINSVILLE
RIO VISTA
ISLETON
SAN RAFAEL
SAN PABLO
BERKELEY
OAKLAND
STOCKTON
TRACY
TO NORTH BAY AQUEDUCT
TO EAST SIDE CANAL
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
PERIPHERAL CANAL
DRAIN
SCALE IN MILES

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, CFS
①	0
②	25
③	25
④	25
⑤	50
⑥	25
⑦	25
⑧	50
⑨	200
⑩	460
⑪	675
⑫	400

NOTES

1. Mean tidal concentration (mg/l) contours represent steady state conditions
2. Delta outflow 3761 CFS (includes Drain discharge of 460 CFS)
3. Drain nitrogen concentration 21 mg/l

CENTRAL PACIFIC BASINS PROJECT

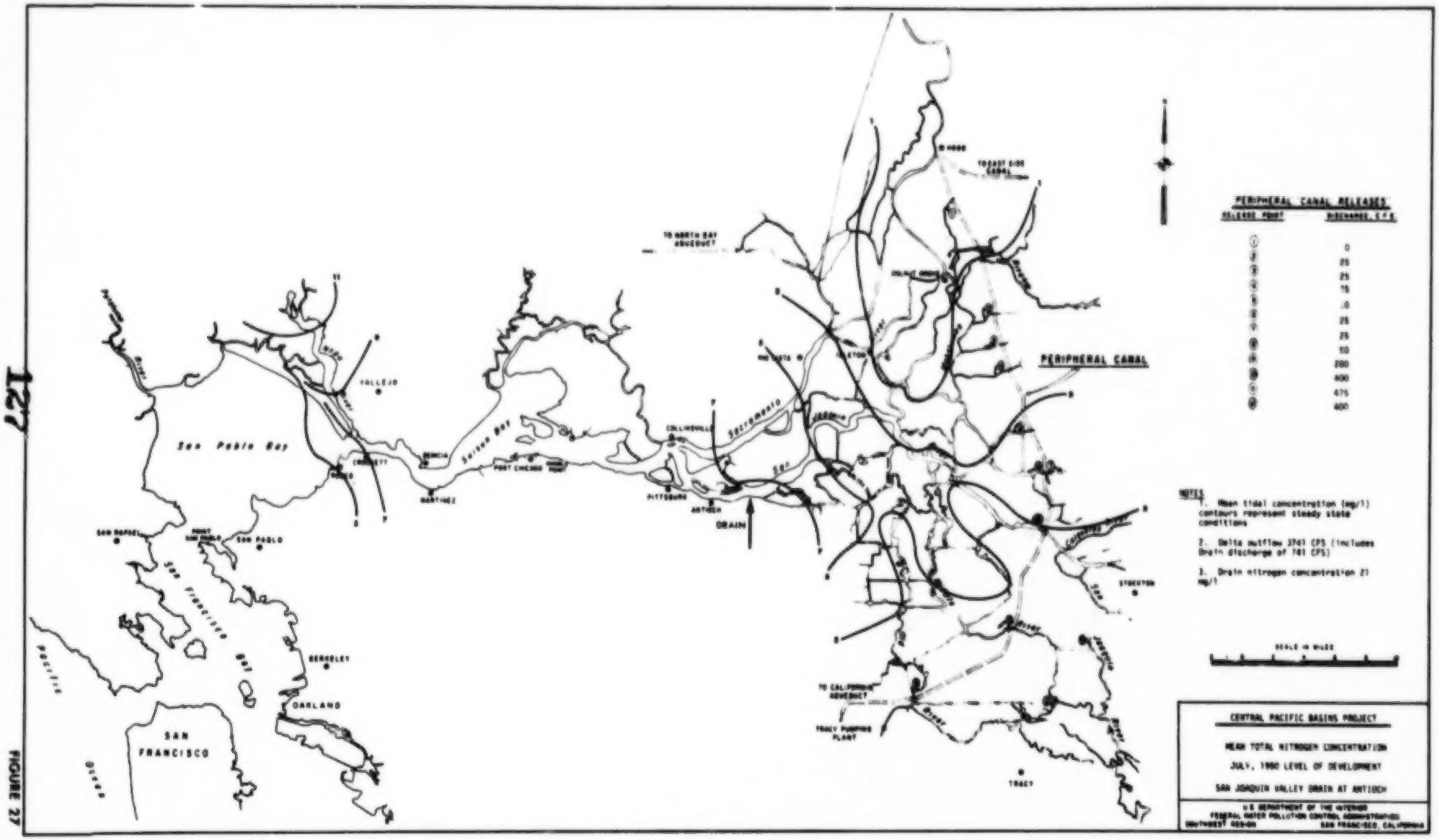
NITROGEN CONCENTRATION FROM DRAIN DISCHARGE

JULY, 1980 LEVEL OF DEVELOPMENT

SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 26



San Pablo Bay
Vallejo
Crockett
Benicia
Suisun Bay
Martinez
Port Chicago
Collinsville
Sacramento
San Joaquin
Pittsburg
Antioch
DRAIN
TO NORTH BAY AQUEDUCT
Rio Vista
HOOD
TO EAST SIDE CANAL
PERIPHERAL CANAL
Stockton
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
TRACY
SAN RAFAEL
POINT SAN PABLO
SAN PABLO
San Francisco Bay
BERKELEY
OAKLAND
SAN FRANCISCO
Pacific Ocean
SCALE IN MILES

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, C.F.S.
①	0
②	25
③	25
④	75
⑤	50
⑥	25
⑦	25
⑧	50
⑨	200
⑩	400
⑪	475
⑫	400

NOTES

1. Mean tidal concentration (mg/l) contours represent steady state conditions
2. Delta outflow 3741 CFS (includes Drain discharge of 781 CFS)
3. Drain nitrogen concentration 21 mg/l

CENTRAL PACIFIC BASINS PROJECT

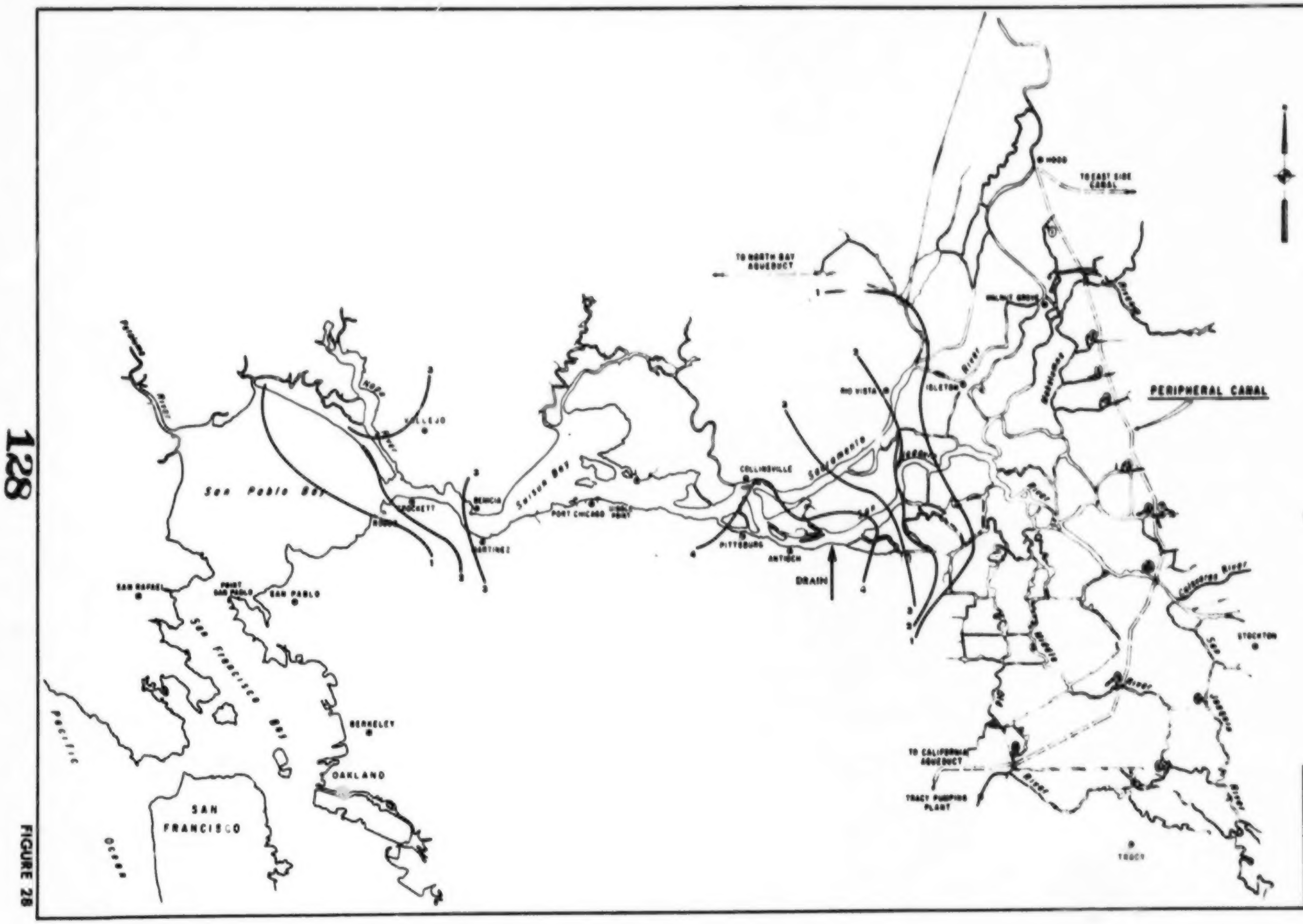
MEAN TOTAL NITROGEN CONCENTRATION

JULY, 1980 LEVEL OF DEVELOPMENT

SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 27


PERIPHERAL CANAL
TO EAST SIDE CANAL
HOOD
WALNUT GROVE
TO NORTH BAY AQUEDUCT
RIO VISTA
ISLETON
Sacramento River
Mokelumne River
Calaveras River
San Joaquin River
STOCKTON
TO CALIFORNIA AQUEDUCT
TRACY PUMPING PLANT
TRACY
DRAIN
COLLINSVILLE
PITTSBURG
ANTIOCH
PORT CHICAGO
Suisun Bay
BENICIA
MARTINEZ
CROCKETT
RODEO
VALLEJO
Napa River
San Pablo Bay
Petaluma River
SAN RAFAEL
POINT SAN PABLO
SAN PABLO
BERKELEY
OAKLAND
San Francisco Bay
SAN FRANCISCO
Pacific Ocean

PERIPHERAL CANAL RELEASES

RELEASE POINT	DISCHARGE, C F S
①	0
②	25
③	25
④	25
⑤	50
⑥	25
⑦	25
⑧	50
⑨	200
⑩	400
⑪	475
⑫	400

NOTES

1. Mean tidal concentration (mg/1) contours represent steady state conditions

2. Delta outflow 3741 CFS (includes Drain discharge of 741 CFS)

3. Drain nitrogen concentration 21 mg/1

SCALE IN MILES

CENTRAL PACIFIC BASINS PROJECT

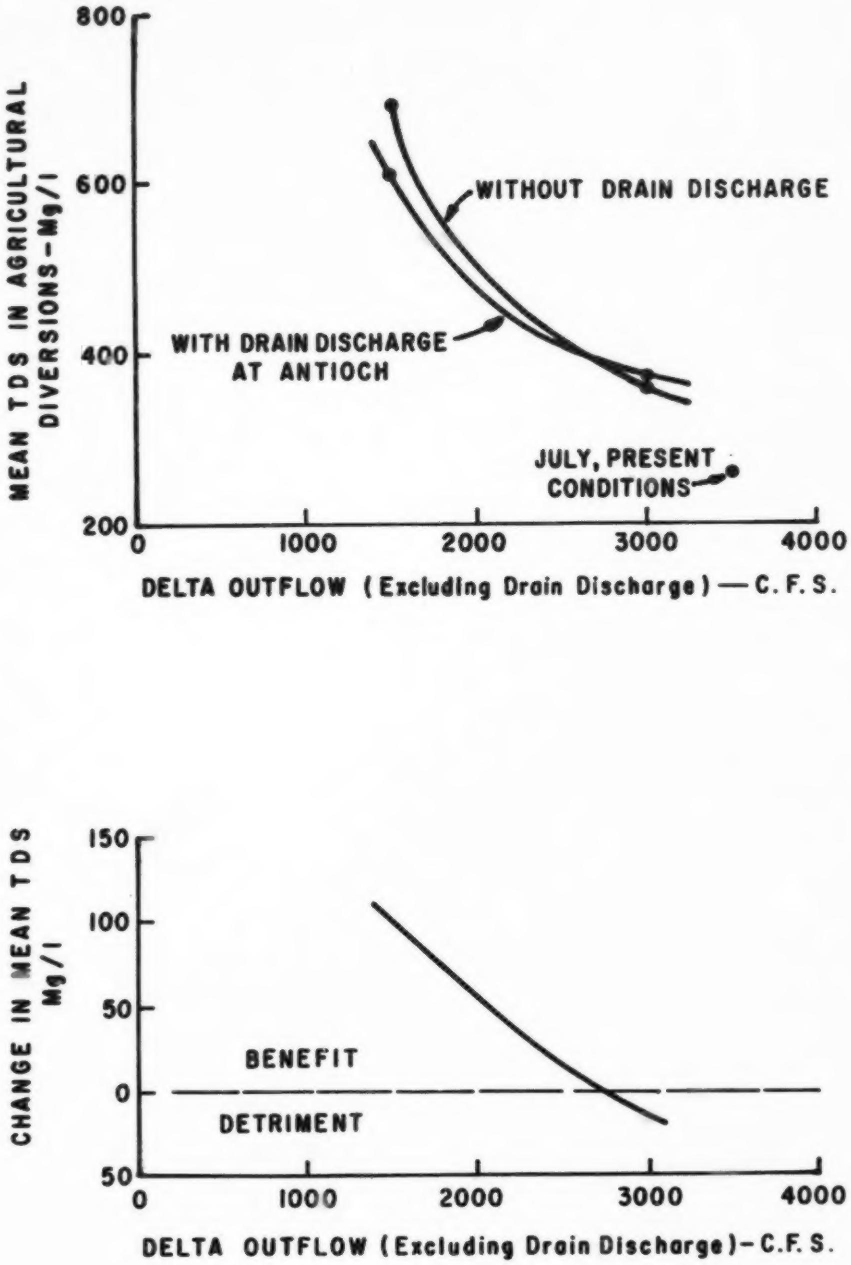
NITROGEN CONCENTRATION FROM DRAIN DISCHARGE

JULY, 1980 LEVEL OF DEVELOPMENT

SAN JOAQUIN VALLEY DRAIN AT ANTIOCH

U S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 28

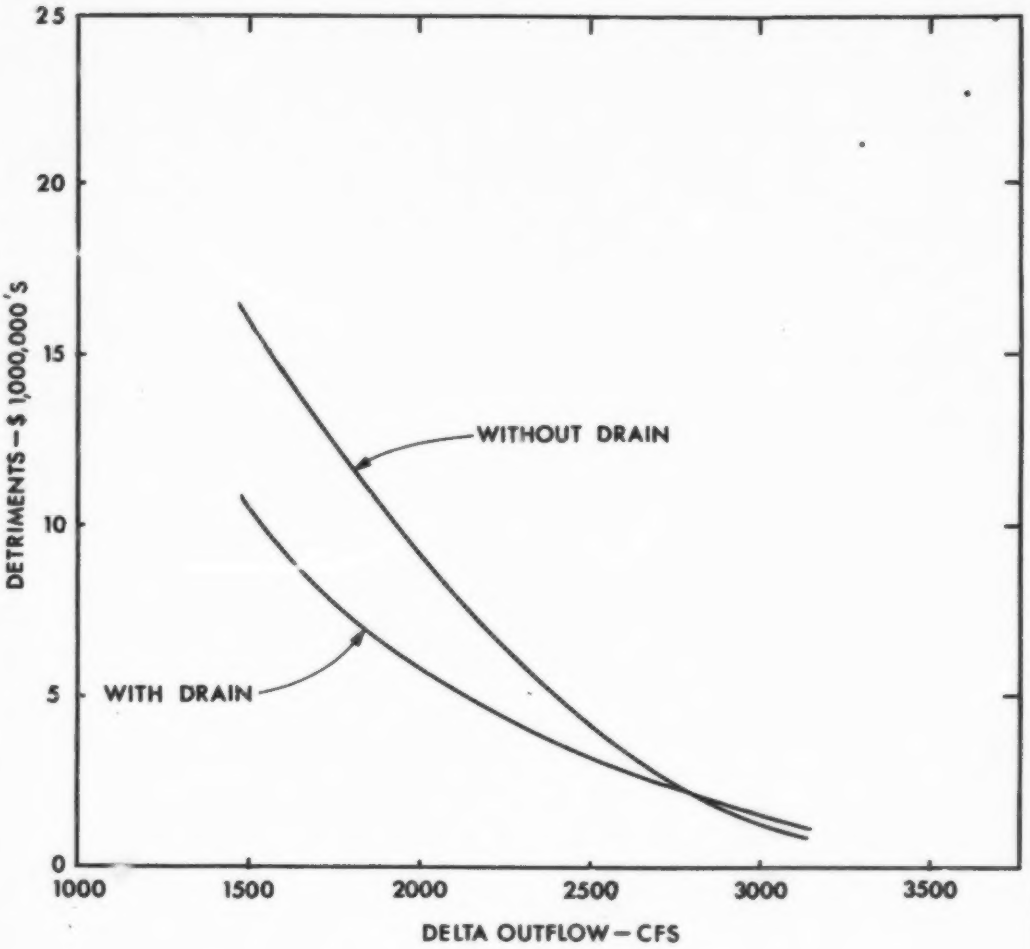


CENTRAL PACIFIC BASINS PROJECT

INFLUENCE OF DELTA OUTFLOW
ON MEAN TDS
OF DELTA AGRICULTURAL WATER
JULY, 1990 CONDITIONS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 29

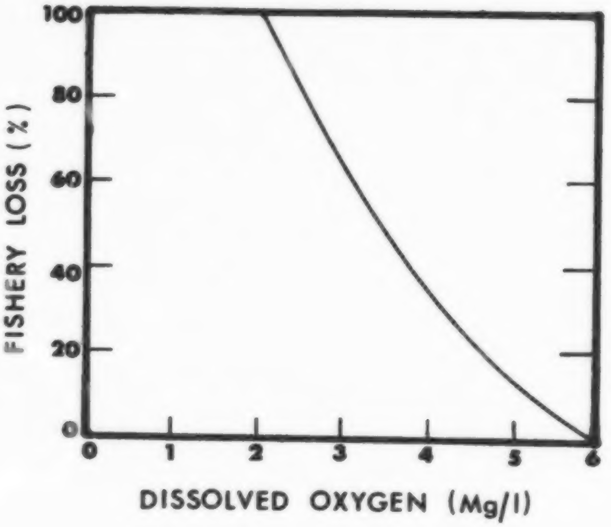


CENTRAL PACIFIC BASINS PROJECT

SALINITY DETRIMENTS
TO AGRICULTURE VERSUS
DELTA OUTFLOW
1990 CONDITIONS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 30

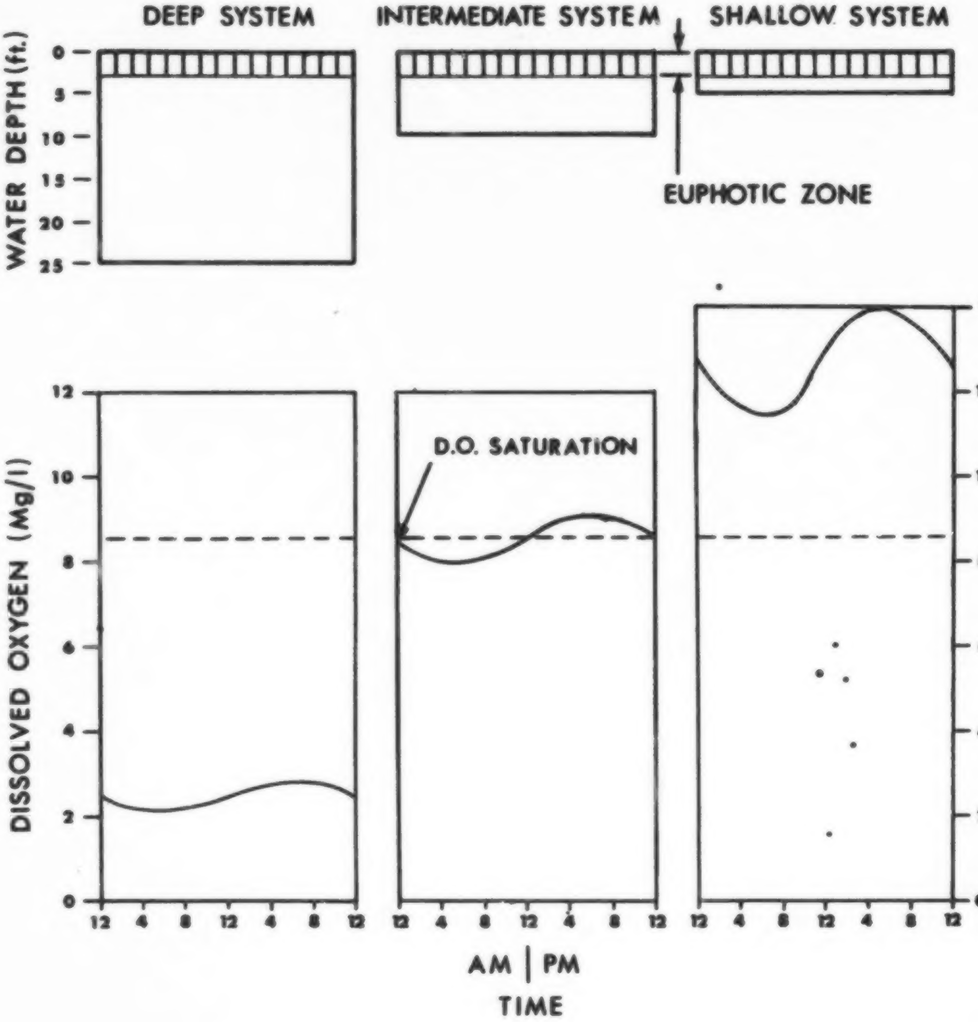


CENTRAL PACIFIC BASINS PROJECT

FISHERY SURVIVAL

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 31



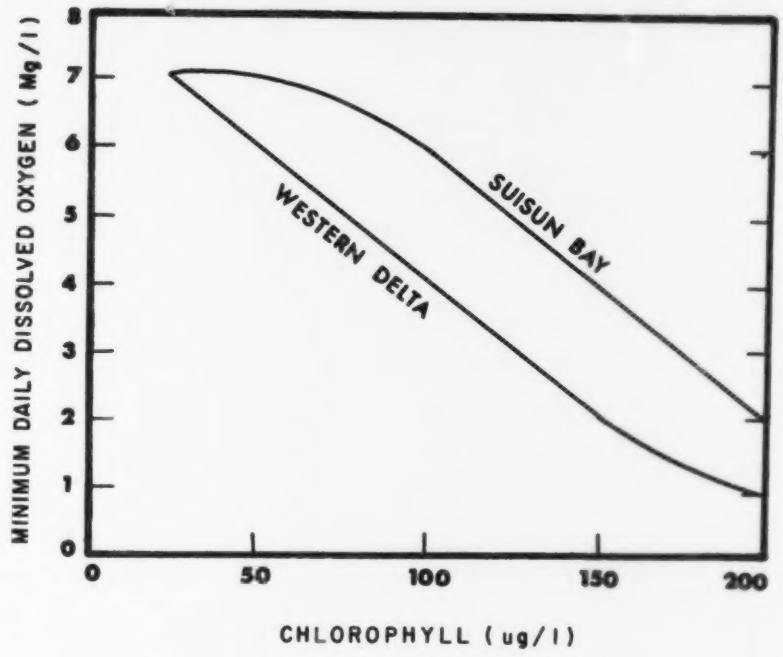
All examples based on constant respiration and gross production for 100 ug/l Chlorophyll.

CENTRAL PACIFIC BASINS PROJECT

TYPICAL DIURNAL
DISSOLVED OXYGEN VARIATIONS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION
SAN FRANCISCO, CALIFORNIA

FIGURE 32

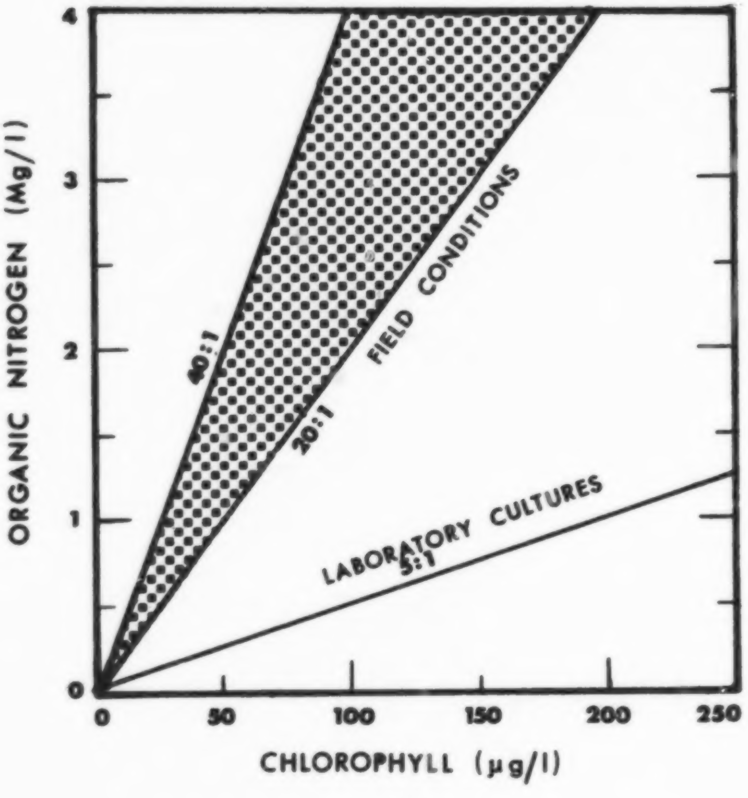


CENTRAL PACIFIC BASINS PROJECT

DISSOLVED OXYGEN — CHLOROPHYLL RELATIONSHIP

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 33

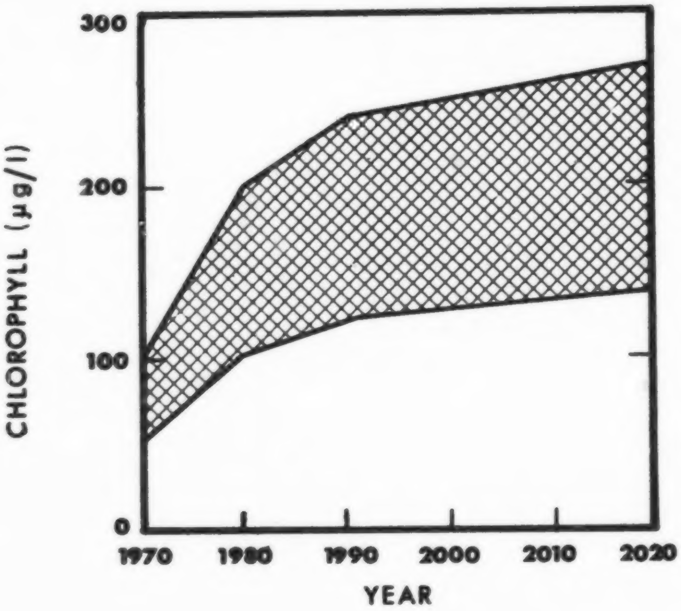


CENTRAL PACIFIC BASINS PROJECT

NITROGEN CHLOROPHYLL
RATIOS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 34

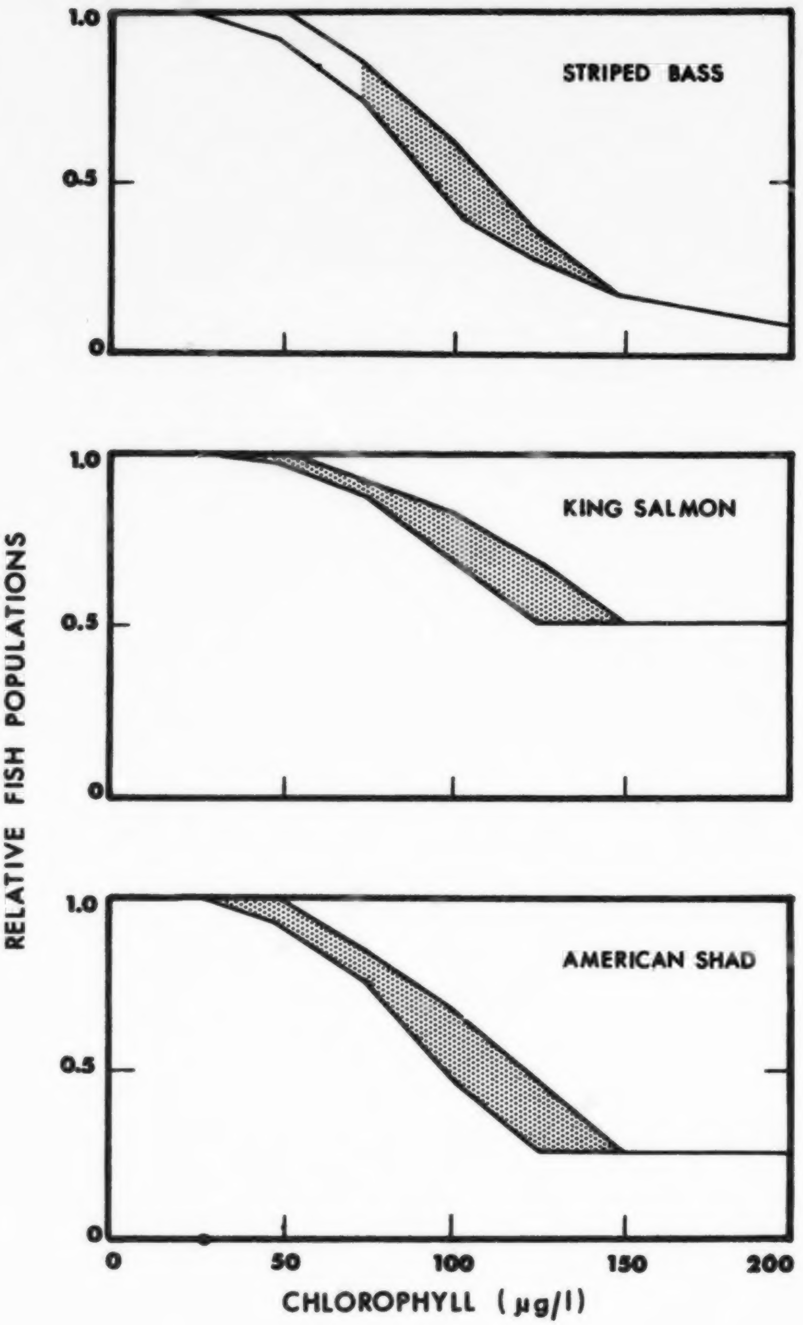


CENTRAL PACIFIC BASINS PROJECT

PROJECTED CHLOROPHYLL
CONCENTRATIONS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 35

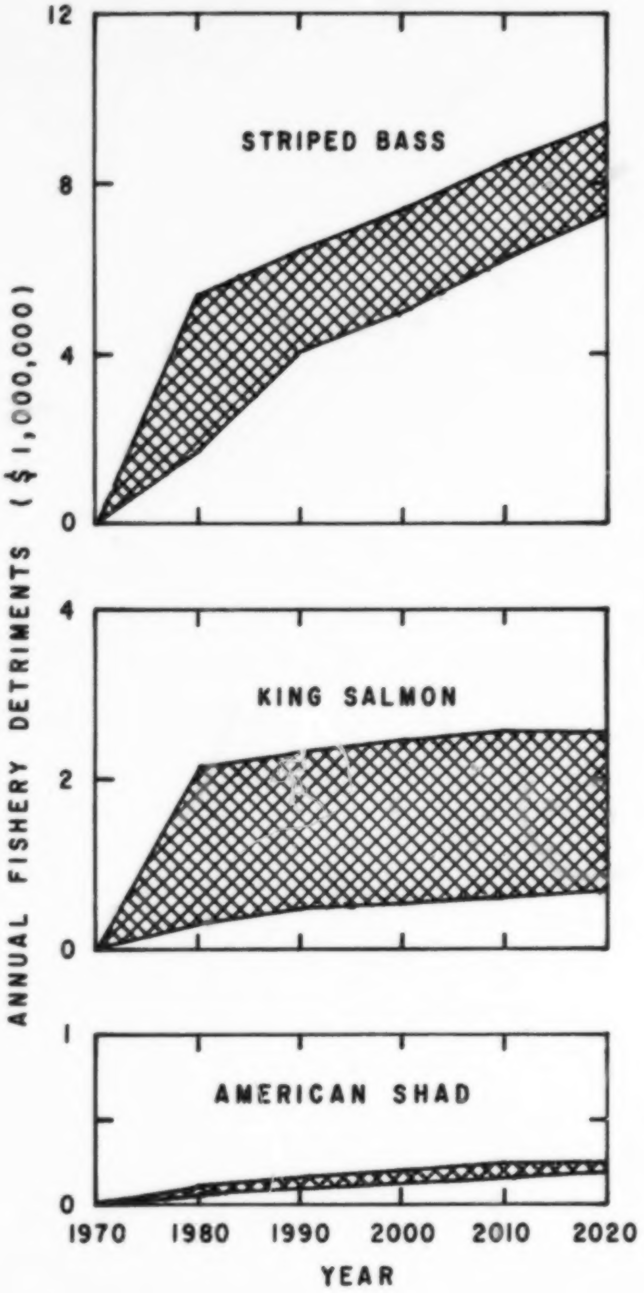


CENTRAL PACIFIC BASINS PROJECT

RELATIVE FISH POPULATIONS
VS
CHLOROPHYLL

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 36

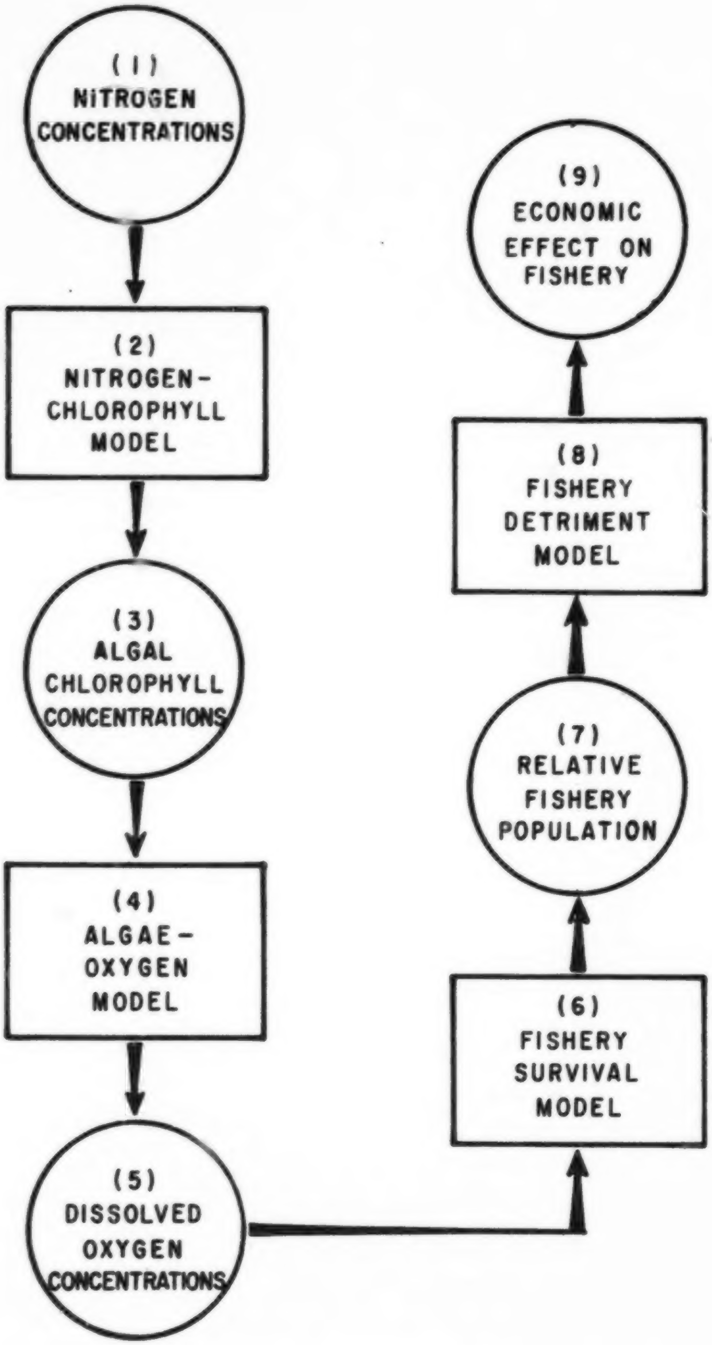


CENTRAL PACIFIC BASINS PROJECT

PROJECTED FISHERY DETRIMENTS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

FIGURE 37


(1)
NITROGEN
CONCENTRATIONS
(2)
NITROGEN-
CHLOROPHYLL
MODEL
(3)
ALGAL
CHLOROPHYLL
CONCENTRATIONS
(4)
ALGAE-
OXYGEN
MODEL
(5)
DISSOLVED
OXYGEN
CONCENTRATIONS
(6)
FISHERY
SURVIVAL
MODEL
(7)
RELATIVE
FISHERY
POPULATION
(8)
FISHERY
DETRIMENT
MODEL
(9)
ECONOMIC
EFFECT ON
FISHERY

CENTRAL PACIFIC BASINS PROJECT

COMPONENTS OF
FISHERY DETRIMENT
PREDICTIONS

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
SOUTHWEST REGION SAN FRANCISCO, CALIFORNIA

PO 974-239

FIGURE 38